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Status of the Cockburn Sound Crab Fishery

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Explanatory note:
This report reflects research information and data collected up to the end of 2010 and management information up to and including the 2009/2010 season. It does not include data or advice beyond this period. It also summarises information published in papers on the Cockburn Sound fishery by de Lestang et al., 2010 and Johnston et al., 2011. For further research and management information, please refer to the most current *State of the Fisheries and Aquatic Resources Report* available from the Department of Fisheries.

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Contents

Abstract

Cockburn Sound

Blue swimmer crabs (*Portunus armatus*) (formerly Portunus pelagicus; Lai et al., 2010) in Cockburn Sound, Western Australia, are the basis of an important commercial and recreational fishery close to the Perth metropolitan area with the commercial fishery achieving a peak catch of 362 t in 1997/98 and a recreational catch of about 18 t. Commercial blue swimmer crab catches declined significantly since 2000 due to low stock abundance, resulting in the closure of the fishery in December 2006. The fishery remained closed for 3 years with predicted catches, based on juvenile recruitment indices, indicating that recovery had been slow. Like many other blue swimmer crab fisheries, management relied on controls on fishing effort and on a minimum legal size set well above the size at sexual maturity to allow crabs to spawn at least once before entering the fishery ; this was presumed to provide adequate protection to the breeding stock. However, a combination of biological, environmental and fishery-dependent factors contributed to a collapse and included: 1) vulnerability to environmental fluctuations as Cockburn Sound is at the southern extreme of this tropical species' temperature tolerance, 2) a life cycle contained within an embayment and self-recruiting, 3) a change in fishing method from gill nets to traps which increased fishing pressure on pre-spawning females in winter and reduced egg production to one age class, 4) four consecutive years of cooler water temperatures resulting in poor recruitment, and 5) continued high fishing pressure during years of low recruitment resulting in low breeding stock.

The strength of recruitment (juvenile 0+) during April-August from the previous season's spawn (September to January), and the residual stock (1+) near the completion of the current fishing season (July-August), have been incorporated in an abundance index that indicates the size of the next season's breeding stock and predicts the commercial catch. This catch prediction has been used in the development of a draft decision-rule framework for the future management of this fishery to determine the appropriate amount of fishing effort.

Water temperatures at the start of the spawning season positively influence the strong stock-recruitment relationship for *P. armatus* in Cockburn Sound. Warm water temperature at the onset of spawning results in the larger females producing additional broods of eggs, and therefore a far greater number of larvae over the short spawning season. This relationship helped explain the variations in recruitment and the reason for the collapse and provides information essential for the development of biological reference points for management.

Current Stock Status for 2009 – 2010

Assessment of data during 2009 suggested that the recovery of crab stocks in Cockburn Sound was sufficient to allow a precautionary approach to re-opening the fishery for the 2009/10 season. The fishery was re-opened with a reduced season length from 10 months to 3.5 months (December 15, 2009 to March 31, 2010), 20% trap reduction and an increase in commercial size limit from 130 to 140 mm CW, with the recreational fishery size limit remaining at 127 mm CW. Under this limited management regime, a total commercial catch of 56 t was recorded

for the 2009/10 season. The CPUE for the 3.5 month period averaged 0.91 kg/trap lift, with a steady decline in catch rate occurring from December (1.15 kg/traplift) to March (0.8 kg/traplift). This refected the decline in numbers of crabs above 140 mm CW. The full complement of traps was utilised (640 traps), with very little latent effort in the fishery during the 2009/10 season. A recreational survey was conducted to estimate crab catch during the 2009/10 season with data currently being analysed.

During the 2009/10 season the sex ratio changed slightly from historical trends with ovigerous females dominating the catch for longer during the summer months (January 64% vs 28% pre-closure and February 33% vs 14% pre-closure) with a late switch to males in February, with females dominating the catch from April onwards (54-72%).

In 2010, there has been a large increase in the juvenile index reflecting the large recruiting (0+) cohort that was evident in research trawls. Juvenile abundance at Colpoys Pt and CBH Jetty has been the highest since the fishery closed in 2006 with numbers in April and June significantly higher than the average number recorded in those months in the years preceding closure (2001-2005). However, variability is high with abundance in March, May and July approximately half that of April and June. Although large numbers of juveniles are evident in 2010, the level of recruitment is still just below historic average levels and the size of recruits is smaller than previous years. This may have implications for commercial fishing in 2010/11 with a potentially lower proportion of recruits moulting to a size large enough to be captured at last year's legal size of 140 mm CW.

A preliminary estimate of the 2010 juvenile and residual index has predicted a commercial catch of 349 t for the 2010/11 season (assuming historical levels of fishing) which is a significant increase from the catch prediction of 220 t for the 2009/10 season. The residual abundance for 2010 after the limited opening season has been maintained at a good level. The egg production index of 2009/10 suggests for the first time since the closure of the fishery that the breeding stock levels may be adequate. Based on the decision-rule framework a precautionary expansion to the fishery is suggested using the option of reducing the minimum size to 135 mm CW, and/or increasing season length to end of April.

Genetic Studies

Genetic studies have indicated that the population of blue swimmer crabs in Cockburn Sound is generally independent from other stocks in the State, for example the Peel-Harvey estuary, Geographe Bay, Dongara and Shark Bay. A genetic assessment of the relationships among the assemblages of the blue swimmer crab in Cockburn Sound, the adjacent Swan River Estuary and near-by Warnbro Sound in south-western Australia was undertaken by Chaplin and Sezmis (2008). The assessment was based upon the patterns of variation at four polymorphic microsatellite loci in samples of *P. armatus* collected from Cockburn Sound, Swan River Estuary and Warnbro Sound in 2007 and 2008. Results indicated that the genetic compositions of the assemblages of *P. armatus* in Cockburn Sound, the Swan River Estuary and Warnbro Sound were homogeneous at the time of sampling and thus *P. armatus* is represented by either a single biological stock, or a series of overlapping stocks, in these water bodies. On the basis of all of the available information, Chaplin and Sezmis (2008) tentatively concluded that the amount of gene exchange between the assemblage of *P. armatus* in Cockburn Sound and those in the Swan River Estuary and Warnbro Sound is temporally variable and generally insufficient to have major impact on the abundance of this species in any of these water bodies, i.e., that *P. armatus* is represented by a series of overlapping stocks (rather than a single stock) in these water bodies.

Swan River and Warnbro Sound

A commercial monitoring program commenced in the Swan River and Warnbro Sound crab fisheries in 2007 to enable a comparison with the fishery in Cockburn Sound. Catches in both fisheries fluctuate significantly. In the Swan River catches range from 6-28 t (1990-2009, mean 16 t) with 10 t taken in 2009. Most crabs are taken over summer with catches between May and November contributing only 10% of the catch. Males dominate the catch over summer before a switch in sex ratio to non-berried females by the end of May. Berried females and juvenile crabs are noticeably absent from catches. Crabs are characterized by their large size and dark colour and fetch premium prices.

Annual catches in Warnbro Sound have fluctuated between <1 t – 17 t (1990-2009) generally following level of fishing effort with 16 t taken in 2009. Males dominate the catch over summer with non-berried females forming bulk of the catch from March to September. Unlike Swan River and consistent with Cockburn Sound, berried females occur between September and January and juveniles are evident in the catch.

Recreational catch in the Swan River and Warnbro Sound

Several surveys quantifying recreational fishing catch and effort have been conducted in the metropolitan area by the Department of Fisheries (DoF) over the past 15 years. However the only survey specifically targeting the Swan-Canning Estuary was a 12-month survey during 1998/99, that estimated the total annual boat-based recreational fishing effort as 22,265 fisher days, with 44 % of this effort targeting blue swimmer crabs. The total annual shore-based recreational fishing effort was estimated to be 8,073 fisher days, with only 9 % of this effort targeting blue swimmer crabs. The estimated total recreational catch of blue swimmer crabs from the Swan-Canning Estuary Basin between August 1998 and July 1999 inclusive was 20,875 crabs or 7.3 tonnes. This consisted of a boat-based catch of 20,176 crabs and a shore-based catch of 699 crabs. Most crabs (94%) kept by recreational fishers were male. There have been no dedicated recreational surveys within Warnbro Sound.

1.0 Introduction

1.1 Background

Historically, commercial blue swimmer crab catches in Cockburn Sound have fluctuated dramatically, and were attributed to changes in commercial fishing practices and normal variations in recruitment strength. A recruitment index was developed to measure this variability and to predict the following season's catch (Bellchambers et al., 2006). In 2006, stock assessments for the Cockburn Sound Crab Fishery indicated that, for the third successive year, there had been very low recruitment of crabs. Catches by the commercial fishery had declined sharply from 231 tonnes in 2002/03 to approximately 40 tonnes in 2005/06. This was the lowest annual catch since 1982 and the third successive season below the acceptable catch range of 200-350 t. Recruitment surveys undertaken in 2006 predicted similarly low commercial catches for the 2006/07 season. Analysis of recreational catch data for 2005/06 indicated that the recreational catch had also declined significantly from an average of approximately 18 tonnes to 3 t (Sumner unpublished data). Prior to its decline, Cockburn Sound represented the second largest commercial blue swimmer crab fishery in Western Australia, with catches peaking at 362 t in 1997/98.

In order to avoid further reductions in recruitment and breeding stock, it was necessary to reduce the level of exploitation. A 12-month closure starting December 15, 2006, was agreed to, with a possible extension of two years. Given this course of action more extensive research and commercial monitoring programs were conducted to assess the impacts of the impending management restrictions on recruitment and spawning stock, determine whether crab stocks were recovering to acceptable levels, and determine a management framework for the future management of this fishery.

This report summarises the research undertaken during a three-year Development and Better Interest Fund (DBIF) project, which commenced in March 2007. It also provides background on the biology of blue swimmer crabs in Cockburn Sound, the commercial and recreational crab fishery and the management arrangements that were in place prior to closure of the fishery in December 2006.

In light of the collapse of the Cockburn Sound crab fishery and a lack of data on the blue swimmer crab fisheries in Swan River and Warnbro Sound, a commercial monitoring program for both fisheries was undertaken to provide a basic understanding of stocks. It also aimed to summarise the knowledge of recreational crab catches with surveys undertaken sporadically in each fishery.

1.2 Blue Swimmer Crab Biology in Cockburn Sound

The blue swimmer crab, *Portunus armatus* (A. Milne Edwards, 1861) (formerly *Portunus pelagicus* Linnaeus, 1758; Lai et al., 2010) occurs in nearshore, marine embayment and estuarine systems throughout the Indo-West Pacific region (Stephenson, 1962). They live in a wide range of inshore and continental shelf habitats, including sandy, muddy or algal and seagrass habitats, from the intertidal zone to at least 50 m depth (Williams, 1982; Edgar, 1990). In Western Australia (WA) their distribution extends along the entire coast with the majority of commercial and recreational fishing concentrated in coastal embayments and estuaries between 34^{o} and 24^{o}S. The WA commercial blue swimmer crab fishery is the largest in Australia, with a total commercial catch of 888 t valued at $4.4 million in 2007/08 (Johnston and Harris, 2009). They are also a highly valued species to recreational fishers, and represent the most important recreationally fished in terms of participation rate. Commercial fishing pressure and popularity with recreational fishers (Sumner et al., 2000) is placing considerable pressure on *P. armatus* stocks in some areas of the state. One such area is Cockburn Sound; a shallow marine embayment located 20 km southwest of Perth (Fig 1.1).

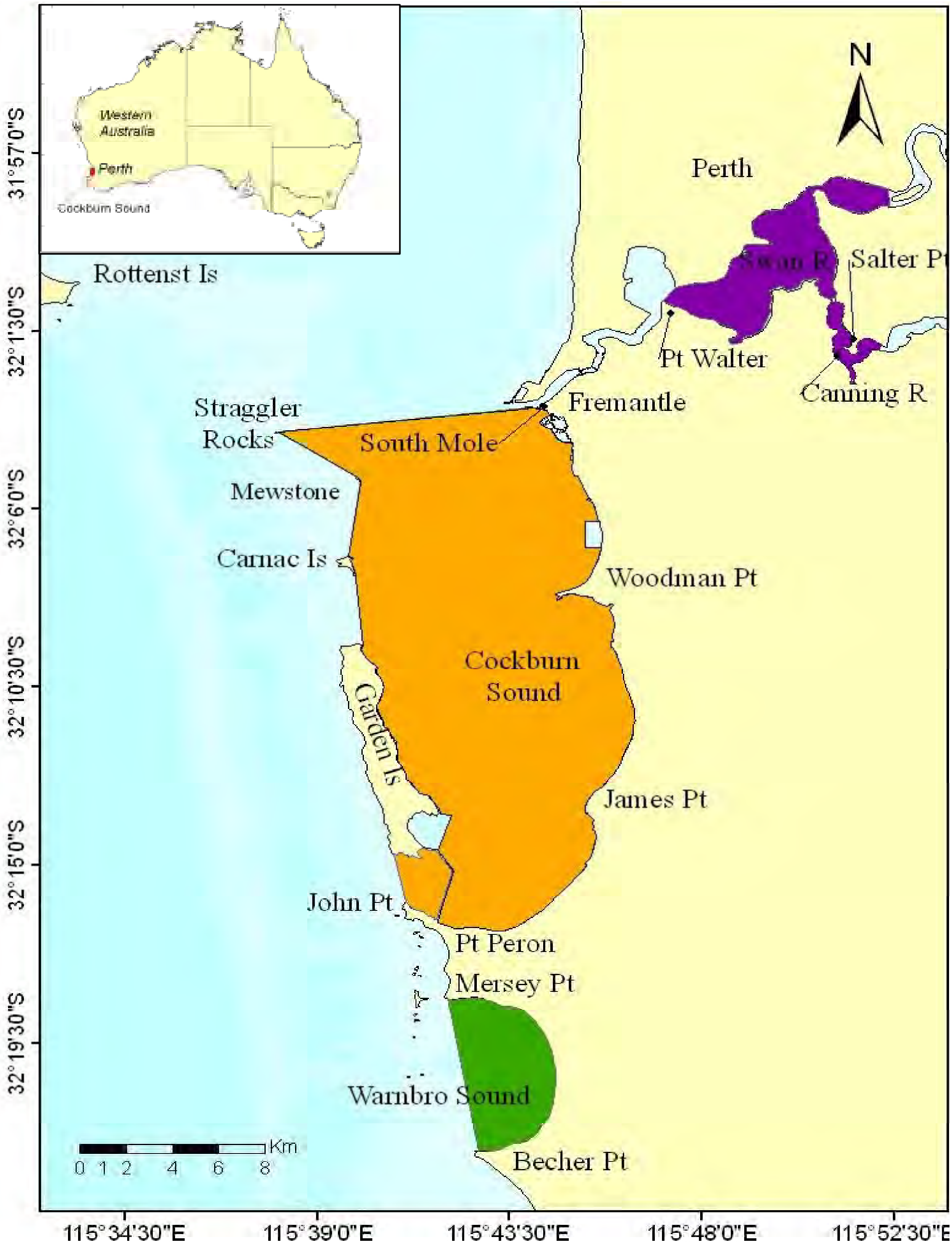

Figure 1.1. Map of Cockburn Sound showing extent of the commercial blue swimmer crab fisheries of Cockburn Sound (■), Warnbro Sound (■) and (Area I of the West Coast Estuarine Managed Fishery (Swan-Canning Estuary)) (■).

The reproductive cycle of blue swimmer crabs within Cockburn Sound is influenced strongly by water temperature, as these waters are at the southern extreme of this species temperature range (de Lestang et al., 2010). Consequently the spawning period is restricted to spring/summer, whereas in more tropical waters, like Shark Bay, spawning occurs year round (de Lestang 2003b). In Cockburn Sound, mating occurs in late austral summer – autumn (January to April), when females have finished spawning and recently matured juveniles are soft-shelled (Kangas, 2000). These females store the sperm for a number of months over winter, after which eggs are extruded and fertilised, with females becoming ovigerous and spawning between October and January (Penn, 1977; Smith, 1982). Incubation takes 10 to 18 days, depending upon water temperature and the larval phase extends for up to six weeks, with larvae drifting as far as 60 km out to sea, before settling inshore (Kangas, 2000). Rapid growth occurs over summer during the juvenile phase, with juveniles able to be caught by trap/trawl between March and June after which they move into the deeper waters of the basin in Cockburn Sound. In Cockburn Sound, size at maturity generally is less than minimum legal size (130 mm CW commercial and 127 mm CW recreational) and occurs in summer (January-April) when they are approximately 14-18 months of age. Most animals in exploited crab stocks have died either through natural or fishing mortality by the time they are 20 months old (Potter *et al*., 2001), but without fishing pressure, blue swimmer crabs can live for three to four years.

Genetic studies have indicated that the population of blue swimmer crabs in Cockburn Sound is generally independent from other stocks in the State, for example the Peel-Harvey Estuary, Geographe Bay and Dongara (Chaplin *et al*., 2001). This implies that it is unlikely there would be pronounced recruitment of blue swimmer crabs from outside of Cockburn Sound into this embayment. Hence, adverse changes in environmental conditions or high levels of fishing pressure in the embayment could have highly detrimental and long-term effects on crab stocks in Cockburn Sound (Chaplin *et al*., 2001). Recent research has shown that crab populations in Cockburn Sound, and adjacent locations, Swan River and Warnbro, are genetically similar, although it is believed that limited mixing of stocks occurs between these adjacent water bodies (Chaplin and Sezmis, 2008).

1.3 Physical Description of Cockburn Sound

Cockburn Sound (32°10'S, 115°43'E), located 20 km southwest of Perth, is an embayment 15 km long, 10 km wide and is about 100 km^2 in area (Fig 1.1). The shallow and fringing waters of this protected marine embayment, which expand outwards to form the expansive Southern Flats (2-4 m deep) in the south-west and the Parmelia and Success banks (4-6 m deep) in the north, surround a large basin in which water depths range from 17-24 m. The above banks are covered by dense beds of *Posidonia sinuosa, Posidonia australis* and *Amphibolis antarctica*, whereas the substrate in the deep basin consists mainly of unvegetated bare sand and silt (Potter *et al*., 2001). Cockburn Sound receives little freshwater discharge from rivers or streams with the input of freshwater restricted to that derived from rainfall and groundwater and storm drain discharge (Hutchinson and Moore, 1979). Consequently salinity remains close to full strength seawater (35 ppt) most of the year.

1.4 History of the Fishery - Management

The Cockburn Sound (Crab) Managed Fishery encompasses the inner waters of Cockburn Sound, from South Mole at Fremantle to Stragglers Rocks, through Mewstone to Carnac Island and Garden Island, along the eastern shore of Garden Island to South-West Point and back to John Point on the mainland (Fig 1.1). The Warnbro Sound (Crab) Managed Fishery includes Warnbro Sound itself and adjacent waters, extending from Becher Point in the South to John Point in the North although actual fishing is restricted to between Becher Point and Mersey Point (Fig. 1.1).

1.4.1 Commercial Fishery

Commercial crab fishing in Cockburn Sound started in the 1970s and traditionally used gill nets. Few restrictions were placed on commercial fishing activities other than a prohibition on taking berried females and a minimum size limit (130 mm CW commercial and 127 mm CW recreational). As fishing pressure increased, the need for a comprehensive management plan became apparent, and the *Cockburn Sound Crab Management Plan* was introduced in 1995. In 1994/95 the fishery was converted from gill nets to purpose-designed traps to reduce the impact on non-target species (Fig. 1.2). The fishery was managed through input controls which regulated fishing methods and gear specifications, seasonal and daily time restrictions, retainable species, minimum size limits and the number of licences. Due to their increased efficiency, the total number of traps allowed in the fishery has been reduced

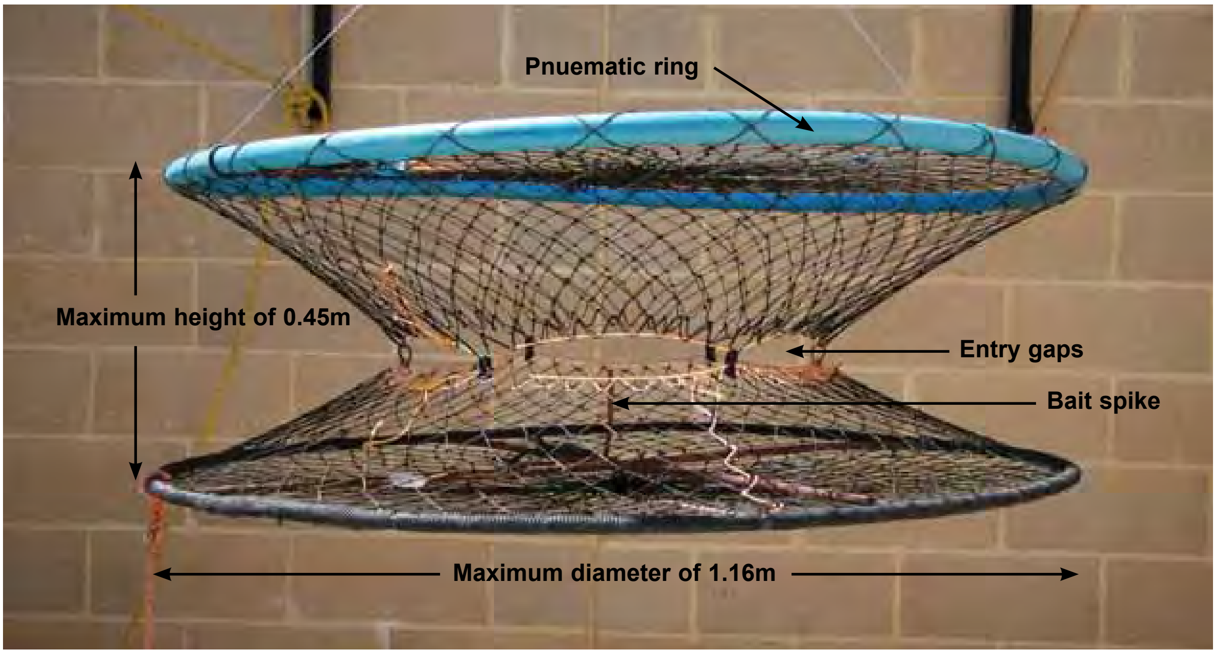

Figure 1.2. Hourglass trap used by commercial blue swimmer crab fishers in Cockburn Sound.

several times, from 1600 in 1998 to 800 in 2003/04 through catch share arrangements designed to increase the recreational sector's share of total catches (Melville-Smith et al., 1999). The conversion between net and trap proved difficult due to the seasonal variation in catchability between the gear types. The nets were mainly suitable for fishing in summer, while traps have been shown to be suitable in summer and winter.

The principal management tool to ensure adequate breeding stock at this time involved minimum size limits set well above size at sexual maturity (de Lestang et al., 2003a). This allowed crabs to spawn at least once prior to entering the fishery and under average recruitment was thought to provide adequate protection to breeding females. Commercial fishers operated from 1 December to 30 September, with a closed spawning season between 1 October and 30 November (introduced in 1999) to protect the berried females that are present in the Sound in large numbers at that time of year. Prior to the closure of the fishery in December 2006 there were 12 license holders sharing a total allocation of 800 crab traps.

Commercial traps can only be pulled once every 24-hour period (commencing at midnight) and commercial fishers must comply with time closures within the fishery and must not pull or set crab pots other than:

(a) during the period commencing on 1 December in any year and ending on 28 February in the following year, between the hours of 03:00 and 12:00 on any day;

(b) during the period commencing on 1 March and ending on 30 June in any one year, between the hours of 03:00 and 13:00 on each day; and

(c) during the period commencing on 1 July and ending on 30 September in any one year, between the hours of 03:00 and 14:00 on each day.

Crab traps must adhere to the following regulations within the fishery (Fig. 1.2):

1. The crab trap has two rings each being of a diameter of not more than 1.16 m;
2. The crab trap when set has a height between the rings of not more than 450 mm;
3. The crab trap has securely fastened to it a tag which is not more than 15 cm in length and not more than 6 cm in height and which clearly displays (in black lettering not less than 6 cm in height) the licensed fishing boat number of the authorized boat from which the crab trap was used;
4. The crab trap, or another crab trap attached to the first crab trap by means of not less than 20 m of negatively buoyant rope, has attached to it a negatively buoyant rope to which is attached one float having a diameter of not less than 190 mm and which float clearly displays in characters not less than 80 mm in height and 15 mm in width the licensed fishing boat number of the authorized boat from which the crab trap is being used; and
5. The tag and float must specify the licensed fishing boat number of that boat. A person must not use two or more crab traps that are joined together unless the tags and float specify the same details.

1.4.2 Spatial Distribution of Commercial Crab Fishing

Spatial analysis of catch monitoring data pooled from 1999-2006 indicates that nearly all of the available area in Cockburn Sound south of Woodman Point is subject to commercial exploitation, with fishing effort distributed relatively evenly throughout the embayment (Fig. 1.3). Fishing tends to be confined to the deeper water (>10 m), although the fringing waters of Jervois and Mangles Bay provide a significant proportion of the catch. Traditionally, the areas of the fishery north of Woodman Point provide a small portion (5-10%) of the annual catch. Berried females are often found in large numbers in deep waters east of Garden Island and west of James Point.

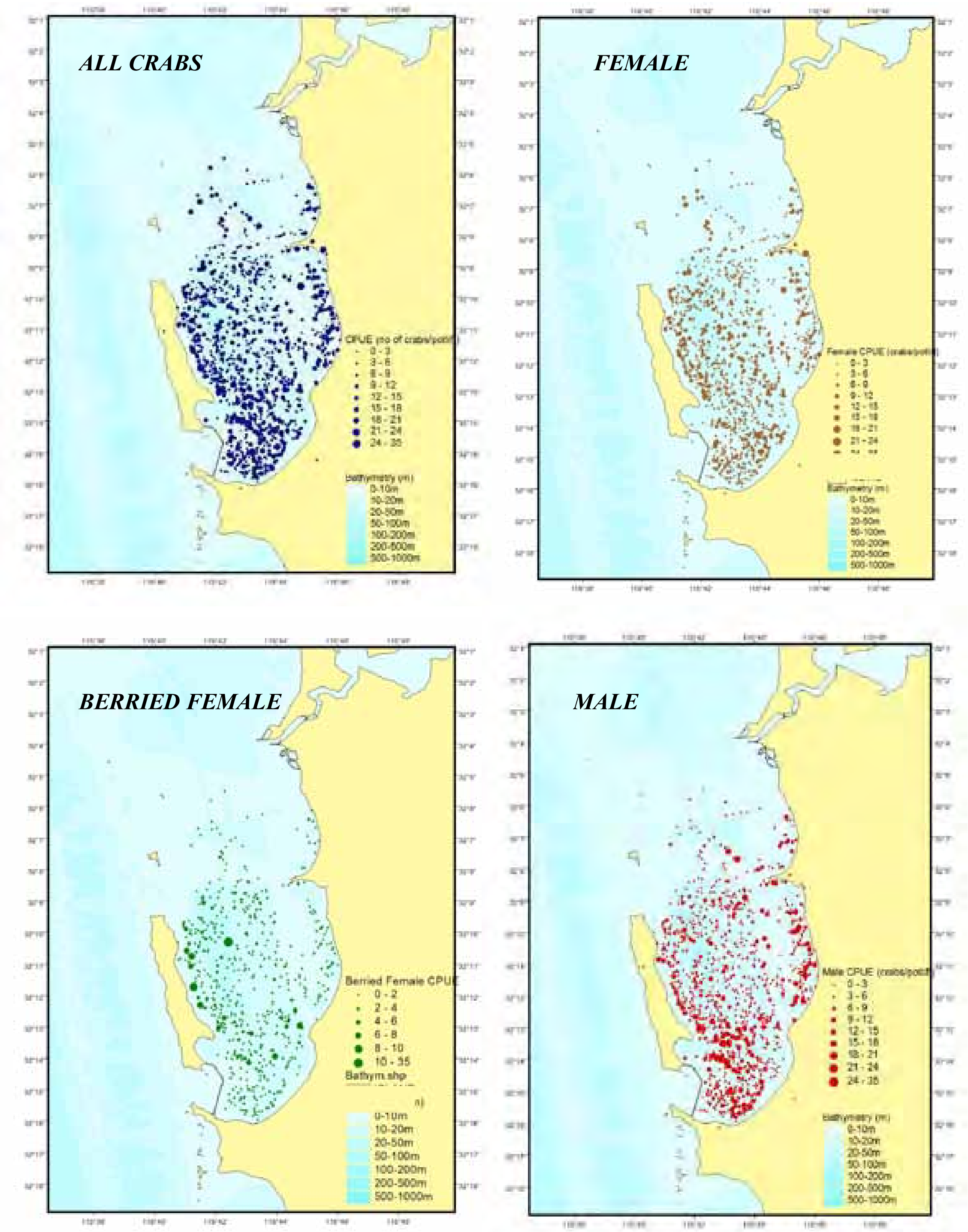

Figure 1.3. Spatial distribution of blue swimmer crabs caught in Cockburn Sound during catch monitoring surveys aboard commercial vessels between 1999 and 2006.

1.4.3 Recreational Fishery

Blue swimmer crabs are targeted by recreational fishers, particularly in the estuaries and embayments between Fremantle and Albany and around Nickol Bay in the Pilbara. They represent the most important recreational inshore species in the south-west of Western Australia in terms of numbers caught. While the majority of recreational fishers use either drop nets or scoop nets, diving for crabs is also common, particularly in Cockburn Sound.

Due to its close proximity to Perth, Cockburn Sound is popular with recreational crab fishers. While commercial catches can be quantified from monthly fishers returns, data available for recreational fishers in Cockburn Sound is restricted to a limited number of surveys. The recreational sector of the fishery is regulated by bag limits (20 per person and 40 per boat reduced to currently 10 and 20, respectively), a minimum size of 127 mm CW and the prohibition of retaining berried females. Gear is restricted to wire or plastic scoop nets, drop nets or hand-held blunt wire hooks. Recreational catches have ranged between 18 and 23 t, representing between 5% and 15% of total catch (Sumner and Williamson, 1999; Sumner and Malseed, 2004; Bellchambers et al., 2005). However, by the mid 2000s recreational catch had declined significantly in line with commercial catch. A boat-based creel survey conducted over the peak recreational period (Jan – Mar) in 2006 produced a recreational catch estimate of 3 t (Sumner, unpubl. data).

A summary of recreational survey data for the crab fishery in Cockburn Sound is presented in Appendix 2 of this report. Detailed methods for a survey conducted between 15 Dec 2009 – 31 March 2010 (first season open since closure of the fishery) is also presented. Data is currently being analysed.

1.5 Resource Sharing Agreements

To address concerns over allocation of the crab resource in Cockburn Sound, resource-sharing agreements were established in 1999 to restabilise and reallocate catches back to the recreational sector, including a 5/8 (62.5%) allocation to commercial fishers and 3/8 (37.5%) catch allocation to recreational fishers. Regulations to try and achieve this were a larger legal size limit (130mm carapace width) for commercial fishers, compared with 127mm CW for recreational fishers in 1998 and restricting the number of commercial traps used in the fishery to 800 in 2003/04 (from 1600 in 1998).

The commercial effort restrictions were successful in contributing to an initial increase in the proportion of total catches taken in Cockburn Sound by the recreational sector, from 8% in 1996/97 to 15% in 2001/02 (Sumner and Malseed, 2004), but the catch share remained below the 3/8 (37.5%) allocated. Bellchambers *et al*. (2005a) subsequently illustrated that the proportion taken by the recreational sector declined to 9.3% in 2003 and 12.3% in 2004. Although recreational crabbing effort was steady between 1996/97 to 2002, recreational fishing effort in 2003 and 2004 decreased. In contrast, commercial fishing effort increased from 143,319 trap lifts in 2002 to 183,049 and 173,756 trap lifts in 2003 and 2004. Therefore, despite a net rise in both commercial and recreational catch rates between 2002 and 2004, the share taken by the recreational sector decreased over this period because of a reduction in the amount of recreational fishing effort and an increase in commercial fishing effort.

1.6 Swan River and Warnbro Sound

While blue swimmer crabs represent the largest component of commercial and recreational catches in the Swan-Canning Estuary and Warnbro Sound, the population status of crab stocks in these fisheries is largely unknown. Historically, the only data available on commercial catch came from monthly catch and effort statistics (CAES) returns, which indicate commercial catch was highly variable (Smith, 2006). Unfortunately this data does not provide important biological information on the crab population such as length frequency, sex ratio, number of berried females and juveniles that is essential for understanding the population status. Given that these two crab fisheries are in close proximity to Cockburn Sound it was possible that they may have experienced a similar decline in population numbers. The relationship between the three populations was also unclear, although it was likely that some Swan River crabs migrate into and out of Cockburn Sound. It was important to determine the status of, and relationship between, each crab population in order to assess whether separate management arrangements were required for each fishery.

Compared to Cockburn Sound, the commercial blue swimmer crab fisheries in Swan River and Warnbro Sound are small. They are managed through a combination of input and output controls similar to the Cockburn Sound fishery, primarily through the regulation of vessel and trap numbers. Supplementary controls cover retainable species and associated minimum size limits, seasonal and daily time restrictions and gear specifications. 'Commercial' fishing in the Swan-Canning Estuary commenced shortly after European settlement in 1829 (Smith, 2006). While as many as 130 fishers have operated annually in the fishery, a 'Voluntary Fishery Adjustment Scheme' (VFAS) has reduced the numbers of registered vessels from approximately 30 vessels in the 1960s and 1970s, to just a single fisher in 2009. In line with government policy, the removal of this license is currently being negotiated. The commercial fishery in the Swan-Canning Estuary covers the waters upstream from Point Walter to Heirisson Island on the Swan River, and Salter Point on the Canning River (Fig. 1.1.). A single operator has been endorsed to fish commercially for blue swimmer crabs in Warnbro Sound since 1985. The fisher originally employed gill nets, but began trialing hourglass traps in unison with Cockburn Sound fishers during 1994 and has used them exclusively since the gazetting of the Warnbro Sound Crab Limited Entry Fishery in 1995. The fishery covers the waters of Warnbro Sound inshore from a line drawn from Becher Point in the south to Mersey Point in the north (Fig. 1.1). A spawning closure covers the months of October and November in Warnbro Sound, while fishing is permitted all year round in the Swan-Canning Estuary.

Both areas represent important recreational fisheries, in particular the Swan River where crabs are reportedly much larger and of higher quality than other south-west fisheries. As with the commercial fisheries, both recreational fisheries are managed through a combination of input (gear restrictions) and output (minimum size limit of 127 mm CW; bag limit of 10 crabs per person and 20 crabs per boat) controls.

While the level of commercial effort has fallen in the Swan River and remained constant in Warnbro Sound, the numbers of recreational fishery participants is continuing to grow. Both fisheries are within the Perth metropolitan area and are therefore an important source of crabs to the Perth market and easily accessible to recreational fishers. As a result they attract substantial recreational fishing effort and are under pressure from anthropogenic factors.

1.7 Objectives of DBIF Project

To understand why the crab fishery in Cockburn Sound declined and assess its recovery during closure, a three-year DBIF project was funded commencing in March 2007. Data provided during this project was to be used to advise managers when to open the fishery and the management regime required to ensure adequate protection of the breeding stock in the future. The project was also used to address the lack of biological data on the Swan River and Warnbro Sound fisheries, which were in close proximity to Cockburn Sound and of significant recreational importance. The relationship between the three populations of crabs was unknown and important for understanding their interaction and whether separate management strategies were needed for each fishery.

The objectives of the project were as follows:

- Monitor the number of recruits (juveniles) during and after closure of the fishery (through continuation and expansion of the juvenile trawl survey) to update the catch prediction model for 2007/08, 2008/09 and 2009/10 and assess the impact of closure on recruitment recovery.
- Examine densities of all age classes of blue swimmer crabs (recruits and spawning stock) in Cockburn Sound (through continuation and expansion of research trawling by the *R.V. Naturaliste)* to assess overall population status and recovery.
- Determine the length frequency, sex ratio and proportion of berried females in the crab population of Cockburn Sound during and after closure of the fishery (through commercial catch monitoring) to assess the strength of the 2006/2007, 2007/2008 and 2009/2010 recruiting cohort and breeding stock for determining the speed of recovery by the fishery.

The DBIF objectives on Cockburn Sound have been addressed in a paper "*Johnston, D., Harris, D., Caputi, N. and Thomson, A. 2011. Decline of a blue swimmer crab (Portunus pelagicus) fishery in Western Australia – history, contributing factors and future management strategy". Fisheries Research* (Chapter 2). The purpose of this paper was to: 1) document the catch history of the blue swimmer crab fishery in Cockburn Sound, 2) outline the key factors that contributed to its collapse, 3) refine the juvenile (0+) index developed by Bellchambers et al., (2006) to include a greater number of recruitment areas and a residual stock (1+) component for predicting future catches during closure and recovery, 4) propose a decision rule framework to guide the future management of this fishery to ensure sustainability.

A stock-recruitment-environment relationship was also developed by de Lestang et al. (2010) to address the relative contribution of the environment and breeding stock to the collapse of the Cockburn Sound fishery in 2006. This paper (Chapter 3) provides important information on the Cockburn Sound crab fishery that are relevant to the DBIF objectives. "*de Lestang, S., L.M. Bellchambers, N. Caputi, A.W. Thomson, M.B. Pember, D.J. Johnston, and D.C. Harris. 2010. Stock-Recruitment-Environment Relationship in a Portunus pelagicus Fishery in Western Australia. In: G.H. Kruse, G.L. Eckert, R.J. Foy, R.N. Lipcius, B. Sainte-Marie, D.L. Stram, and D. Woodby (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks. doi: 10.4027/bmecpcc.2010.06."*

The Swan River and Warnbro Sound objectives were to:

- Determine whether crabs in Swan River, Warnbro Sound and Cockburn Sound are the same population (through genetic microsatellite analysis) to assess if separate management measures need to be implemented for each population.
- Determine the length frequency, sex ratio and proportion of berried females in Swan River and Warnbro Sound to assess the population status in each fishery (recruits and spawning stock).
- Investigate whether data is available on recreational crab catch rates for Swan River and Warnbro Sound by examining existing creel surveys, Research Angler and VFLO programs.

Objective 1 for Swan River and Warnbro Sound used genetic microsatellite analysis and was subcontracted to Jenny Chaplin (Murdoch University). The key findings of her report are summarised in Chapter 4 (4.1). (*Chaplin, J. A. & Sezmis, E. 2008. A genetic assessment of the relationships among the assemblages of the blue swimmer crab, Portunus pelagicus, in Cockburn Sound, the Swan River Estuary and Warnbro Sound. Final Report prepared for the Department of Fisheries, Western Australia. Centre for Fish and Fisheries Research, Murdoch University*). Objectives 2 and 3 are reported in Chapter 4 (4.2 and 4.3).

Chapter 5 summarises the current stock status of the fishery and updates some of the results presented in chapter 2 and 3. The management options for the 2010/11 based on the decision-rule framework are also outlined.

2.0 Decline in the blue swimmer crab stocks of Cockburn Sound – history, contributing factors, recovery and future management strategy.

Johnston, D., Harris, D., Caputi, N. and Thomson, A.

2.1 Abstract

Commercial blue swimmer crab (*Portunus armatus*) catches in Cockburn Sound, Western Australia, have declined significantly since 2000, due to low stock abundance resulting in closure of the fishery in December 2006. The fishery has remained closed for 3 years with predicted catches, based on juvenile recruitment indices, indicating that recovery has been slow. Like many other blue swimmer crab fisheries, management relied on a minimum legal size set well above the size at sexual maturity to allow crabs to spawn at least once before entering the fishery to presumably provide adequate protection to the breeding stock. However, a combination of biological, environmental and fishery-dependent factors contributed to a collapse and include: 1) vulnerability to environmental fluctuations as this species is at the southern extreme of its temperature tolerance, 2) a life cycle contained within an embayment and is self-recruiting, 3) a change in fishing method from gill nets to traps which increased fishing pressure on pre-spawning females in winter and reduced egg production to one age class, 4) four consecutive years of cooler water temperatures resulting in poor recruitment, and 5) continued high fishing pressure during years of low recruitment resulting in low breeding stock. The strength of recruitment (juvenile 0+) from the previous season's spawn (September to January), and the residual stock (1+) near the completion of the current fishing season, have been incorporated in an abundance index that indicates the size of the next season's breeding stock and predicts the commercial catch. This catch prediction has been used in the development of a draft decision-rule framework for the future management of this fishery to determine the appropriate amount of fishing effort. The application of this approach to research and management may assist the sustainability of other blue swimmer crab fisheries at the extreme of their natural distributions.

2.2 Introduction

Commercial catches in Cockburn Sound have fluctuated dramatically, and were attributed to changes in commercial fishing practices and normal variations in recruitment strength (Bellchambers et al., 2006). A juvenile index was developed to measure this variability and to predict the following season's catch (Bellchambers et al., 2006). The commercial catches declined significantly since 2000 and catch prediction for 2006/07 was for a record low catch therefore the fishery was closed to commercial and recreational fishers in December 2006. Prior to its decline, Cockburn Sound represented the second largest commercial blue swimmer crab fishery in Western Australia, with catches peaking at 362 t in 1997/98. The recreational sector of the fishery has been managed through bag limits, with catches between 18 and 23 t, representing between 5% and 15% of total catch (Sumner and Williamson, 1999; Sumner and Malseed, 2004; Bellchambers et al., 2005). Like commercial catch, recreational catch estimates in 2005/06 indicated they had also declined significantly to approximately 3 t (Sumner, unpubl. Data, Department of Fisheries, Western Australia).

The objectives of this chapter were to: 1) document the catch history of the blue swimmer crab fishery in Cockburn Sound, 2) outline the key factors that contributed to its collapse, 3) refine the juvenile (0+) index developed by Bellchambers et al., (2006) to include a greater number of recruitment areas and a residual stock (1+) component for predicting future catches during closure and recovery, and 4) propose a decision-rule framework to guide the future management of this fishery to ensure sustainability. The current status of the stock is provided in Chapter 5.

2.3 Methods

2.3.1 Study site

Cockburn Sound (32.10°S, 115.43°E) is the largest protected marine embayment on the lower west coast of Western Australia, measuring 15 km long and up to 10 km wide with an area ca 100 km^2 (Fig. 2.1). A more detailed description of Cockburn Sound is provided in the Introduction (Chapter 1).

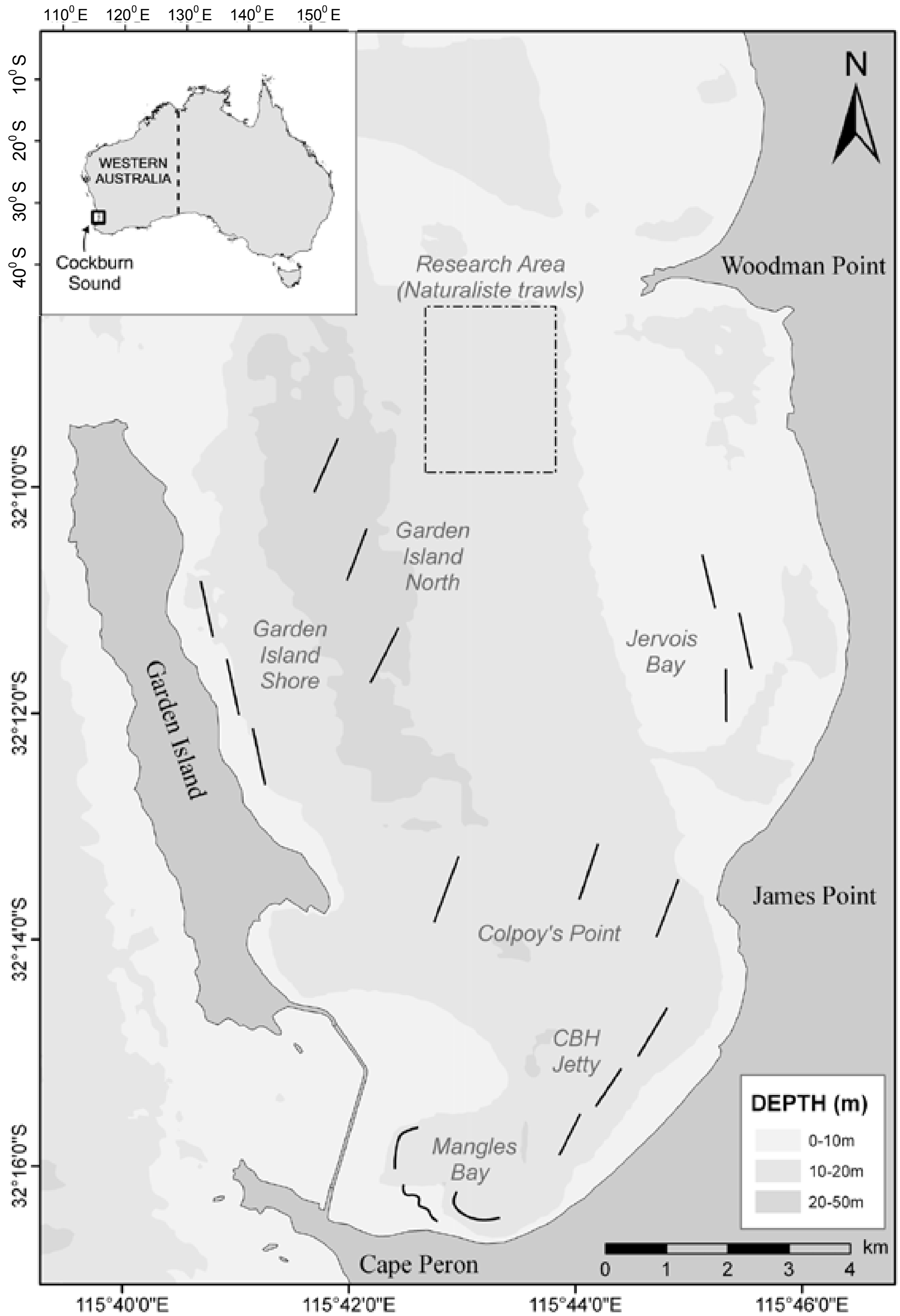

Figure 2.1. Map highlighting the location of Cockburn Sound within Western Australia and the sites sampled during juvenile trawl surveys (**—**) and RV *Naturaliste* trawl surveys within the Research Area conducted by the Department of Fisheries.

2.3.2 Commercial catch and effort

Commercial fishers submit statutory monthly returns that report catch of all retained species and an estimate of fishing effort (days fished per month and mean number of traps used per day in that month). Annual commercial catch (t) and effort (fisher days – total number of days fished per year) in Cockburn Sound are presented by fishing season; 1st December to the following 30th September inclusive, and is referred to as the next calendar year (e.g. the 2001 or 2000/01 fishing season covers December 1st 2000 to September 30th 2001 inclusive). The effort is presented in numbers of fisher days to allow comparison between the two historical fishing methods of netting and trapping.

2.3.3 Commercial monitoring

Monitoring of commercial blue swimmer crab catch and effort has been conducted by research staff since 1999. Commercial fishers were accompanied during daily crabbing operations throughout the fishing season and the day's catch and effort recorded. Each fisher serviced 100-200 hourglass traps (set in lines of 10–20 traps) daily, with all crabbers operating in the fishery surveyed during the season. Monitoring was undertaken on three randomised days during each month of the fishing season between 1999 and 2004, after which two days per month were monitored. Carapace width (the distance between the tips of the two lateral spines of the carapace measured to the nearest millimetre), sex, female berried status (the presence/absence of externally visible eggs protruding from beneath the abdominal flap), the number of traps in the line, soak time (number of hours the traps have been in the water since they were last serviced) and a latitude, longitude and depth for each line were recorded.

Following the closure of the fishery in December 2006, a commercial crab fisher was contracted to replicate commercial fishing in Cockburn Sound. Accompanied by research staff, the fisher set 100 traps in lines of 10, twice a month within the traditional fishing grounds. Standard commercial hourglass traps were used and soak time for all traps was 24 hours.

The commercial monitoring data was used to assess the trend in breeding stock based on catch rates during December, and an index of the abundance of residual (1+) crabs towards the end of the fishing season using catch rates in August-September.

2.3.4 Fishery-independent sampling – breeding stock

Trawling for blue swimmer crabs in Cockburn Sound was conducted aboard the research trawler *RV Naturaliste* (22.7 m length) between 2001 and 2008. The research trawler employed a twin-rig otter trawl, towing nets with a combined headrope length of 12 fathoms (22 m). Each net had 50 mm mesh in the wings and 45 mm mesh in the cod-ends. The nets were demersal with a 10 mm ground chain that was positioned two links in front of the ground rope. A net efficiency factor (0.6 × net headrope length in metres) was incorporated to adjust for the effective spread of the net on the seabed (de Lestang et al. 2003c), giving the effective opening of each net of 7.3 m wide by 1 m high. Trawling was conducted at night and restricted to the Research Area (Fig. 2.1). All trawls were 20 minutes in length with trawling commencing approximately 30 minutes after sunset. Carapace width, sex, and female berried status was recorded. Mean catch rates of sexually mature (86 mm CW and above, de Lestang et al., 2003a) female blue swimmer crabs captured during trawls in the spawning period months September – December, were calculated to provide spawning stock estimates.

2.3.5 Fishery-independent sampling – juveniles

Monthly research trawling to collect data on juvenile crab abundance has been conducted since 2002. Three replicate 750 m trawls were undertaken at up to six different sites during the recruitment period (March to August) each year (Fig. 2.1). Garden Island North, Colpoys Point and CBH Jetty sites were selected on the basis of a historical juvenile trawl program initiated by de Lestang (2003a) and replicated by Bellchambers et al. (2006). The additional sites were selected according to their suitability as juvenile nursery areas within Cockburn Sound to refine the original juvenile index developed by Bellchambers et al. (2006). Sampling was conducted aboard a 7.5 m research vessel, trawling at a speed of 2.8 kts. The trawl net had a headrope of 5 m, with 51 mm mesh panels and 25 mm mesh codend. A net efficiency factor (0.6 × net headrope length in metres) was incorporated to adjust for the effective spread of the net on the seabed (de Lestang et al. 2003c), giving the net an effective opening of 3 m wide by 0.5 m high. Trawling commenced each sample night 30 minutes after sunset, with a warp length to depth ratio of 5:1 observed. The carapace width, sex, and female berried status were recorded. Crabs were allocated to juveniles (0+) and residuals (1+) according to size (using a monthly carapace width that separated the two year-classes obtained from a seasonal von Bertalanffy growth curve) (Bellchambers et al., 2006).

Juvenile blue swimmer crab trawl data collected between 1998 and 2000 (de Lestang 2003a,b) are also presented. Methodology for this monthly trawling replicated that described above, other than sampling was conducted during daylight hours. A period where day-time and night-time sampling overlapped was used to calculate a conversion factor of 6 from daytime trawl catch rates to night time trawl catch rates to standardise between the two datasets. This conversion factor was applied to the data prior to calculating the juvenile index.

2.3.6 Catch prediction model

Catch rates of juveniles (0+; animals caught per 100 m^2 trawled) and residuals (1+; animals caught per traplift) were log transformed i.e. log (catch rate+0.1) before undertaking an ANOVA to take into account the skewed distribution of abundance data. The standardised annual index of abundance of these catch rates was then taken to be the least-squares mean (LSM) (SAS Institute Inc. 1989) of the factor, year, in an ANOVA model. For the juvenile index the model included the main effects of year (1998 – 2009), month (April – June) and location (Mangles Bay, CBH Jetty, Colpoys Point, Jervois Bay, Garden Island North) as well as the two-way interactions of month with year and location. In determining the sites to be used in constructing the juvenile index, only sites that significantly added to the predictive power of the index to model the total catch of the fishery were used. The ANOVA model for residuals (1+) used the main effects of year (1998 – 2009) and month (August-September). The resulting LSMs were back-transformed to an annual standardised index of abundance of juveniles and residuals that take into account the month and location of fishing.

LSMs have been used due to the unbalanced nature of the data (an unequal number of trawls for each site, month and year). Having derived standardised indices for juveniles (0+) ($x_{0,t}$) and residual (1+) ($x_{1,t}$) in year t, the commercial catch (y_t) for season t was modelled as $log(y_t) = a + b\log(x_{0,t-1} + dx_{1,t-1}) + \epsilon_t$ where a, b and d (d is a parameter that adjusts $x_{1,s}$ for having been estimated using data collected by a different method - potting - than that used for estimating $x_{0,s}$ - trawling) are parameters to be estimated, and $\epsilon_t \sim N(0, \sigma^2)$ is the error for season t. This relationship can be used to provide a catch forecast for the upcoming fishing season and an estimate of the catch for seasons that were not fished (2007 to 2009) assuming that fishing effort remained at similar levels throughout the period being assessed.

2.3.7 Decision-Rule Framework

A decision-rule framework using juvenile and residual index data as the biological reference indicator to determine the appropriate level of fishing for the coming season has been developed to assist with the future management of the Cockburn Sound crab fishery. The main management objective was to ensure that fishing effort was commensurate with the juvenile and residual abundance so that a sustainable level of egg production was maintained. A linear relationship comparing the historical percentage of commercial crab catches taken per month prior to the closure (recalculated on a 15 December to 30 June season length) and the combined juvenile and residual index derived for the Cockburn Sound crab fishery catch prediction model is used to set an appropriate length for the commercial season. This assessment takes into account the extension of the closed season of September and October to include July and August in order to reduce fishing on females.

The juvenile (0+) and residual (1+) index generated for the catch prediction model forms the x-axis of the decision-rule framework. The y-axis provides a measure of the mean proportion of annual commercial trap catch that is taken at any given month during the season and is based on historical commercial catch and effort data prior to the closure. This approach determines the minimum level of recruitment and juvenile abundance before fishing is allowed (limit reference point) and the maximum level where the fishery is opened for the whole season (15 December – 30 June) (threshold reference point).

2.4 Results

2.4.1 Commercial catch history

Commercial fishing for blue swimmer crabs in Cockburn Sound began in the 1970s, with fishers setting gill nets primarily through the summer months. Over the next 20 years, annual catch and effort increased steadily from 30 t (687 fishing days) in 1978 to 147 t (2109 fishing days) in 1993 (Fig. 2.2a). In the mid 1990s commercial fishers converted to purpose-designed hourglass traps and annual catch rose dramatically from 129 t in 1994 to 362 t in 1997. From 1996 to 2000, the fishery recorded the five highest annual commercial catches between 220 and 362 t (Fig. 2.2a).

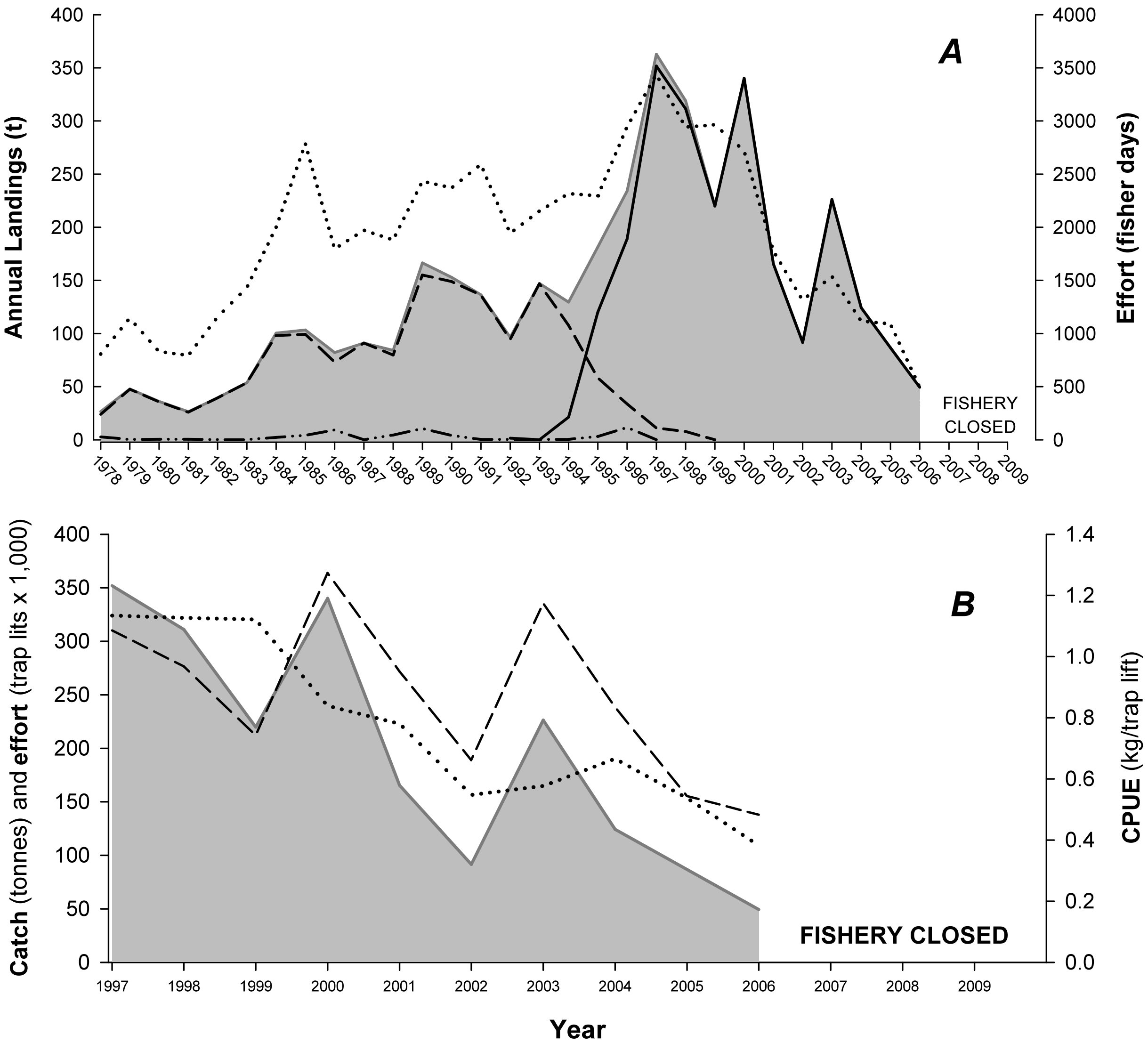

Figure 2.2. **A.** Annual commercial blue swimmer crab catch (t) from the Cockburn Sound Crab Managed Fishery by fishing method and overall effort (fisher days) irrespective of method. Total catch (■); gill nets (- - - - -); crab traps (——); other (– ·· –) and effort (·······). **B.** Annual commercial blue swimmer crab catch (t) (■) from the Cockburn Sound Crab Managed Fishery using traps indicating effort (trap lifts) (·······) and catch per unit effort (kg/traplift) (- - - - -). Annual catch and effort for both A and B is presented as commercial fishing season i.e. 2006 covers the period from December 2005 to November 2006.

While the move from gill nets to hourglass traps resulted in an increase in catch and effort across the commercial season (December to September), the most significant escalation was in the autumn/winter months from April through to the close of the season (Fig. 2.3). Between 1979 and 1994, gill net fishers landed an average 26 t over April-September from a combined 625 fishing days (42 kg/day). Following the conversion from nets to hourglass traps, the mean catch from April to September (1996-2006) increased almost four-fold with trap fishers landing an average 93 t from 969 fishing days (96 kg/day) (Fig 2.3). Hence, the dramatic increase in catch was not solely due to an increase in effort, but also due to the greater efficiency of the purpose-designed hourglass traps.

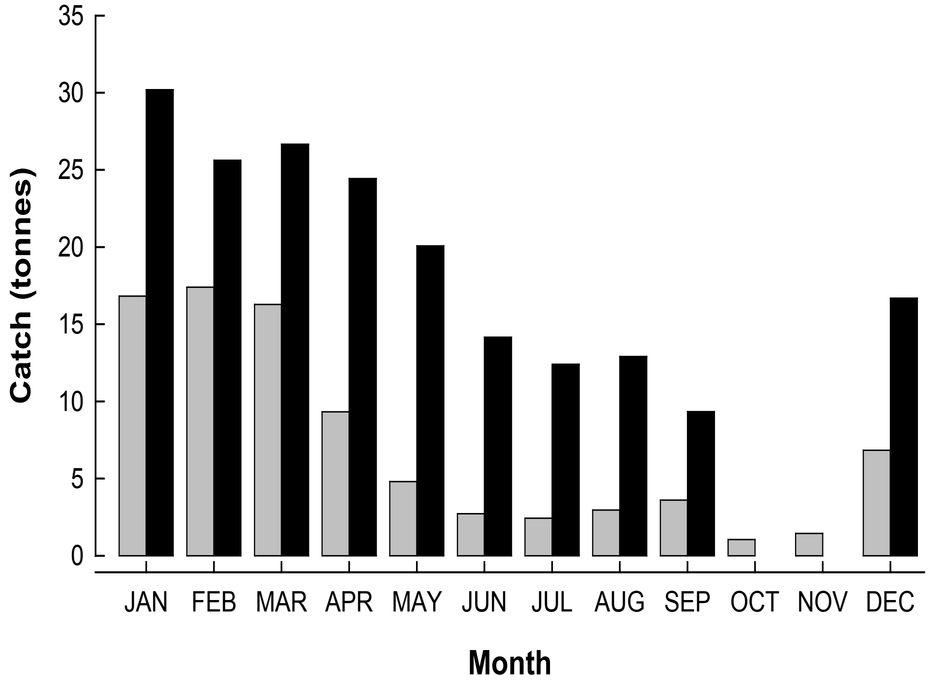

Figure 2.3. Mean monthly commercial blue swimmer crab catch (t) using gill nets (■) between 1977-1994 and hourglass traps (■) in Cockburn Sound between 1996-2006.

Following the second highest annual catch of 340 t in 2000, the catch and catch per unit effort (kg/trap lift) has been in decline (with the exception of 203 t recorded in 2003) with just 50 t and 0.5 kg/traplift recorded in 2006. This represented the lowest annual catch and CPUE since 1982 and resulted in the closure of the fishery to both commercial and recreational fishing (Fig 2.2a, 2.2b).

Most of the annual commercial catch in the Cockburn Sound fishery is taken during the summer months (Fig. 2.3). After beginning in December, 30% of the catch is landed by the end of January, and over half by the end of March. The winter months from June to September contributed less than 25% of the catch.

2.4.2 Trawl surveys

The decline of the commercial blue swimmer crab catch was also reflected in the numbers of crabs collected during research trawl surveys from the Research Area of Cockburn Sound. The *RV Naturaliste* trawl surveys in 2001 showed a mean catch rate of 9.8 crabs.1000m^{-2}, which declined to an average 7.6 crabs.1000 m^{-2} between 2002-2003. The mean trawl catch rate fell to between 1.1 and 2.2 crabs.1000 m^{-2} in 2004-2006 with the fishery closed in December 2006. Since the closure, numbers of crabs captured during research trawl surveys has increased gradually to 4.9 crabs.1000 m^{-2} in 2008.

2.4.3 Catch monitoring

Trends in length frequency analyses were consistent between years, months and vessels and was not greatly influenced by the location of commercial fishing vessels being monitored within Cockburn Sound. Monthly catch monitoring aboard commercial crab vessels show that at the beginning of the season in December, the catch was composed predominantly of female blue swimmer crabs (Fig. 2.4). Within two weeks the catch was divided evenly between male and female crabs, and by January was almost exclusively male (Fig. 2.4). Up to 90% of the female crabs captured during December were ovigerous. Male crabs then dominated the commercial catch through the summer months, with mean proportions declining from 79 % in January to 69 % in March. Over a four-week period in March or April, the catch switched from predominantly male to mainly non-ovigerous female crabs. This high proportion of females in the commercial catch continued through the rest of the season, with mean proportions from April to September increasing from 63 % to 81 % (Fig. 2.4). Ovigerous females first appear in September or October, with spawning triggered by the rise in spring water temperatures.

Regardless of fluctuations in crab abundance, this pattern of variation in sex ratio of the commercial catch was consistent between years. However, during the closure period of the fishery since December 2006, the ratio of male and female crabs caught in traps at different times of the year has changed. Catches during the summer months are still dominated by male crabs, with 69 % to 81 % of the catch being male between January and March (Fig. 2.5). But while female crabs enter traps in March/April, males continue to make up the majority of the catch

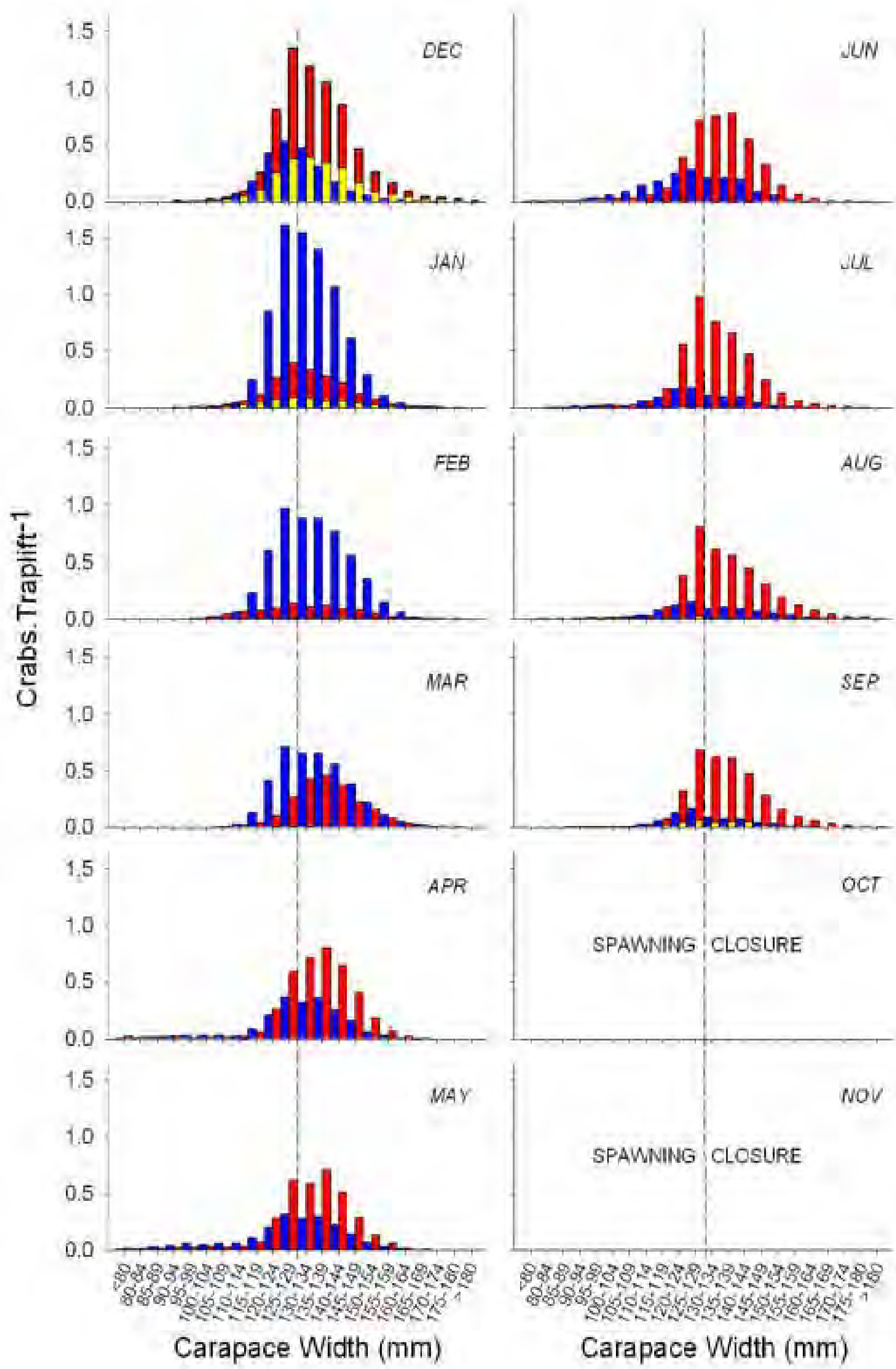

Figure 2.4. Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard commercial vessels in Cockburn Sound between January 1999 to September 2006. Minimum commercial size limit (- - -).

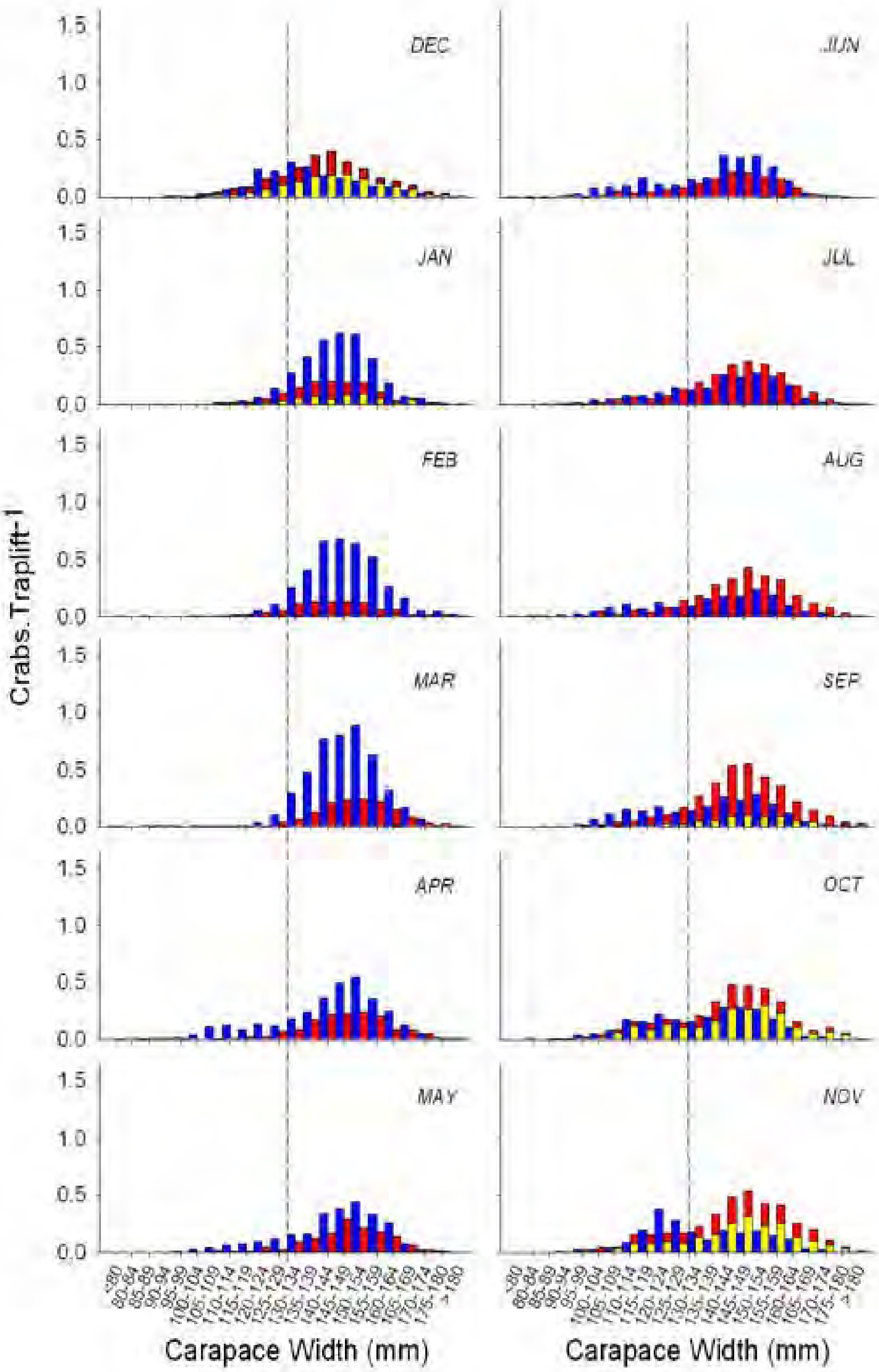

Figure 2.5. Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard a commercial vessel in Cockburn Sound between December 2006 and November 2008. Minimum commercial size limit (- - -).

until June and are caught in significant quantities right through to December when they become dominant in catches again. Prior to the closure, 33 % of crabs caught by the commercial fishery in the month of April were male. Following the closure, the mean proportion of males from April to June rose to between 62 % and 66 % (Fig. 2.5).

Since the closure of the fishery, the size of blue swimmer crabs captured in traps has increased significantly. When the fishery was open, the mean size of males and females in the commercial catch during December was 131 mm CW and 134 mm CW, respectively (Fig. 2.4). As the season progressed, mean size increased slightly through to March (136 mm CW for males; 138 mm CW for females) before decreasing by July to 129 mm CW for males and 133 mm CW for females (Fig. 2.4). Since the closure, crabs captured in December had a mean carapace width of 137 mm CW and 138 mm CW for males and females, respectively, increasing to 148 mm CW for males and 152 mm CW for females by March. But rather than decrease, the mean size of crabs remained relatively constant through to November (Fig. 2.5).

2.4.4 Catch prediction model

Between 1999 and 2002, the juvenile index fell from 4.6 to 1.3 (Fig. 2.6). The index continued to fall to its lowest level in 2006 at just 0.1 (Fig. 2.6). Since the closure of the fishery in December 2006, a modest improvement in the strength of recruitment has been evident increasing to 0.5 in 2008 (Fig. 2.6). Of the variation in juvenile catch rates explained by the factors, year, month, location in the ANOVA, 40% was accounted for by location, verifying the use of multiple recruitment sites in the juvenile index calculation.

The main pulse of crab recruitment to the Cockburn Sound fishery during the period 2002-2005 occurred in autumn from March to May (Fig. 2.7). Between 2002 and 2005, the mean total number of crabs caught was 6 and 15 at the CBH Jetty and Colpoy’s Point sites, respectively, during January and February, with numbers peaking at 130 juvenile crabs in April. Mean total numbers of juveniles captured in trawls at these sites declined by August (Fig. 2.7). The year the fishery closed in 2006, recruitment was low in all months (Fig. 2.7). Post closure, in 2007 and 2008, the numbers of juveniles have increased but the traditional higher abundance pulse between March and May has not been evident, with numbers spread more evenly between March and August (Fig. 2.7).

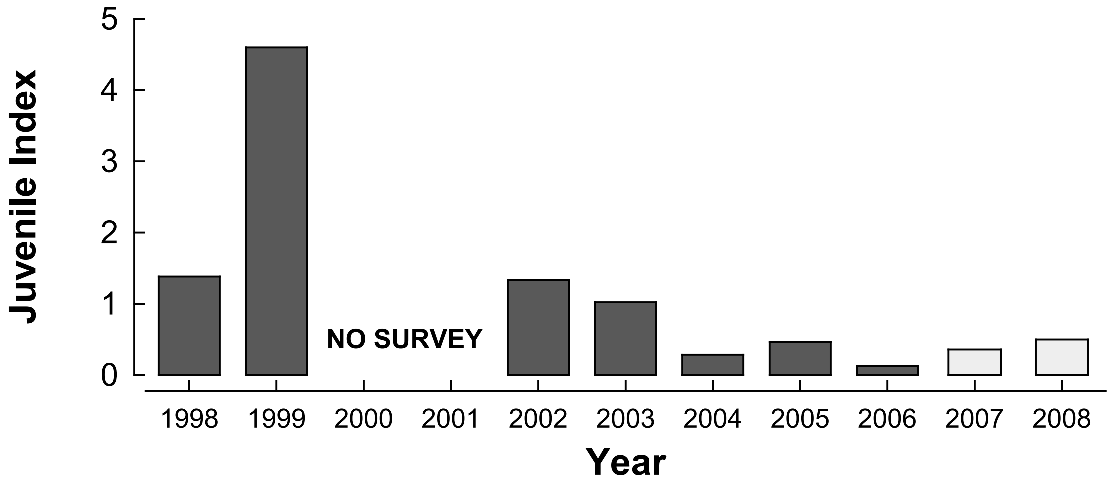

Figure 2.6. Annual standardised index of juvenile recruitment for blue swimmer crabs in Cockburn Sound based on juvenile trawl data collected between April – June at all known juvenile recruitment sites. No juvenile sampling was conducted in 2000 and 2001. Dark grey bars indicate years when sampling occurred whilst the fishery was open; light grey bars indicate years when sampling occurred whilst the fishery was closed.

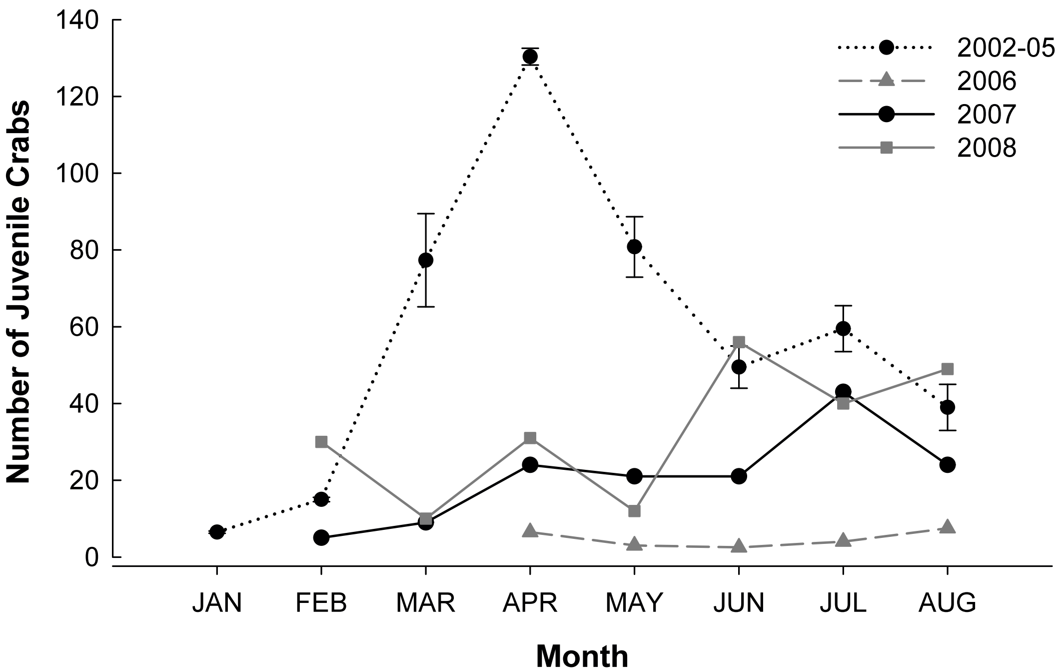

Figure 2.7. Total number of juvenile (0+) blue swimmer crabs captured during monthly trawls at 3 replicate sites at the CBH Jetty and Colpoy's Point in Cockburn Sound. Data between 2002 and 2005 was averaged per month.

A catch prediction model incorporating both the strength of recruitment and the residual stock remaining towards the end of the commercial season has been calculated (Fig. 2.8). The model was used to predict potential commercial catch during the closure, assuming a similar level of effort was maintained, to assess the recovery of the fishery ($R^2 = 0.83$). The parameter, d, of the regression model was 0.29 which provides an estimate of the relative contribution of the recruits and residuals to next year's catch. After a commercial catch of 50 t in the Cockburn Sound crab fishery for 2006, the 2006 juvenile and residual index of 0.74 provided for a predicted commercial catch of just 77 t for the 2007 fishing season. Indicative of the gradual recovery of the Cockburn Sound crab stock, the 2007 index of 1.12 predicted a potential commercial catch of 113 t for the 2008 season, and the 2008 index of 1.59 predicted a commercial catch of 156 t for the 2009 season (Fig. 2.8).

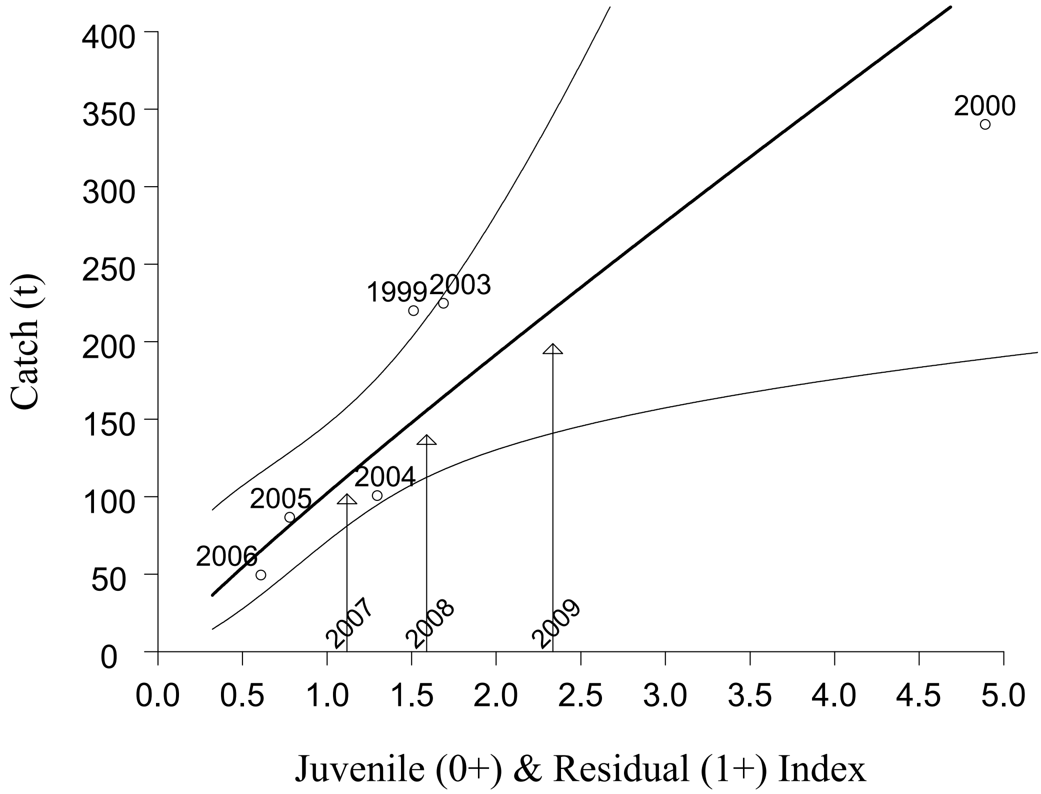

Figure 2.8. The relationship between commercial crab landings and the 0+ (juvenile) and 1+ (residual) index based on data collected from juvenile trawls at recruitment sites sampled in Cockburn Sound between April and June for 0+ (juvenile) and August-September from commercial trap monitoring for 1+ (residuals). The commercial catch for each year (o and labelled with the year of catch) is plotted against the juvenile and residual index from the previous sampling year (eg. point labelled 2006 represents the commercial catch for the 2006 fishing season (Dec 05 – Sept 06) plotted against the juvenile and residual index of the previous year of 0.6). The arrows indicate predicted commercial catch for that year if the fishery had opened, based on the previous year's juvenile and residual index (2007 predicted catch of 77 t based on index of 0.71 from 2006). 95% confidence lines (thin lines) are included for the prediction line (bold line). No data are presented for 1998, 2001 and 2002 as juvenile recruitment surveys were not undertaken in the previous year.

2.4.5 Spawning Stock

The decline and continuing recovery of the blue swimmer crab breeding stock in Cockburn Sound has mirrored the temporal fluctuation described in annual commercial catch and juvenile recruitment. The strength of the breeding stock has been quantified using data from commercial catch monitoring surveys conducted in the Cockburn Sound fishery during December (Fig. 2.9a).

The mean abundance of mature female crabs captured in commercial crab traps during December remained between 6 and 10 crabs.traplift^{-1} from 1999 to 2003. The level of breeding stock fell in 2004 and remained between 2 and 3 crabs.traplift^{-1} through 2007. Only after two years of closure have female numbers improved to 5 crabs.traplift^{-1} in 2008, although these levels are still low compared to earlier years (Fig. 2.9a).

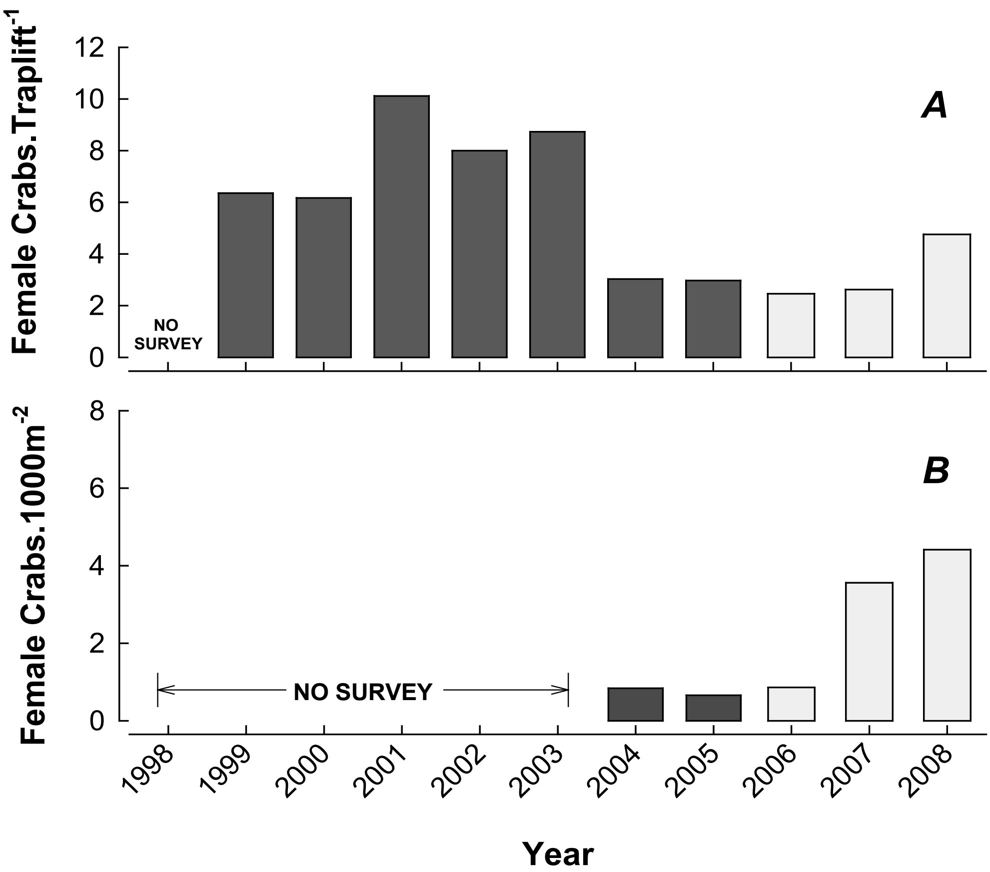

Figure 2.9. ***A.*** Annual mean abundance of sexually mature (86mm CW and above, de Lestang et al., 2003a) female blue swimmer crabs captured from catch monitoring surveys during December aboard commercial crab vessels operating in Cockburn Sound between 1999 and 2008. ***B.*** Annual mean abundance of sexually mature female blue swimmer crabs captured during spawning period months (September – December) from trawl surveys aboard *RV Naturaliste* in the Research Area of Cockburn Sound between 2004 and 2008. Dark grey bars indicate years when sampling occurred whilst the fishery was open; light grey bars indicate years when sampling occurred whilst the fishery was closed.

Despite the limited data set (2004-2008), a recovering trend was also apparent in the mean abundance of sexually mature female blue swimmer crabs captured during spawning period trawl surveys between September and December aboard *RV Naturaliste* in the Research Area of Cockburn Sound. A mean abundance of 0.8 crabs.1000 m^{-2} trawled was recorded in 2004, dropping to just 0.6 crabs.1000 m^{-2} in 2005 (Fig. 2.9b). Numbers of captured mature female crabs has increased moderately to 4 crabs.1000 m^{-2} trawled in 2008 (Fig. 2.9b).

2.4.6 Management - Decision Rule Framework

A draft decision-rule framework to assist with the future management of the Cockburn Sound crab fishery has been developed using juvenile and residual index data calculated from fishery-independent juvenile trawl surveys and fishery-dependent commercial monitoring programs (August and September), respectively, to determine the appropriate level of fishing for the coming season (Fig. 2.10). A linear relationship uses the monthly catch distribution from the pre-closure commercial crab catch history against the annual juvenile and residual index derived for the Cockburn Sound crab fishery catch prediction model to set an appropriate length for the commercial season (Fig. 2.10). For years when the juvenile and residual index is relatively low, the length of season can be manipulated to ensure an adequate proportion of the crab biomass will remain unfished to provide a further buffer for spawning stocks (additional egg production). If the annual juvenile and residual index is below a prescribed level (0.8), the fishery will be closed as the predicted catch will be ≤100 t (Fig 2.9). As the index rises above 0.8, the fishery will open for increased lengths of time. A juvenile/residual index of 1.4, for example, would allow the fishery to open from December 15 to the end of January, while indices of 2.1 and 2.4 would allow the season to remain open until mid March and the end of April, respectively. Once the juvenile and residual index for a particular year is above 2.8, the fishery will open for a full season to the end of June (Fig. 2.10). Finishing the season in June will provide protection to pre-spawning female crabs as fishing through the winter months will no longer occur.

Under this framework, the fishery remained closed during the 2007 season as the juvenile and residual index for 2006 was just 0.13. The 2007 index of 0.37 and 2008 index of 0.59 were again both below the index limit of 0.8, so the fishery remained closed during the 2008 and 2009 fishing seasons (Fig. 2.10).

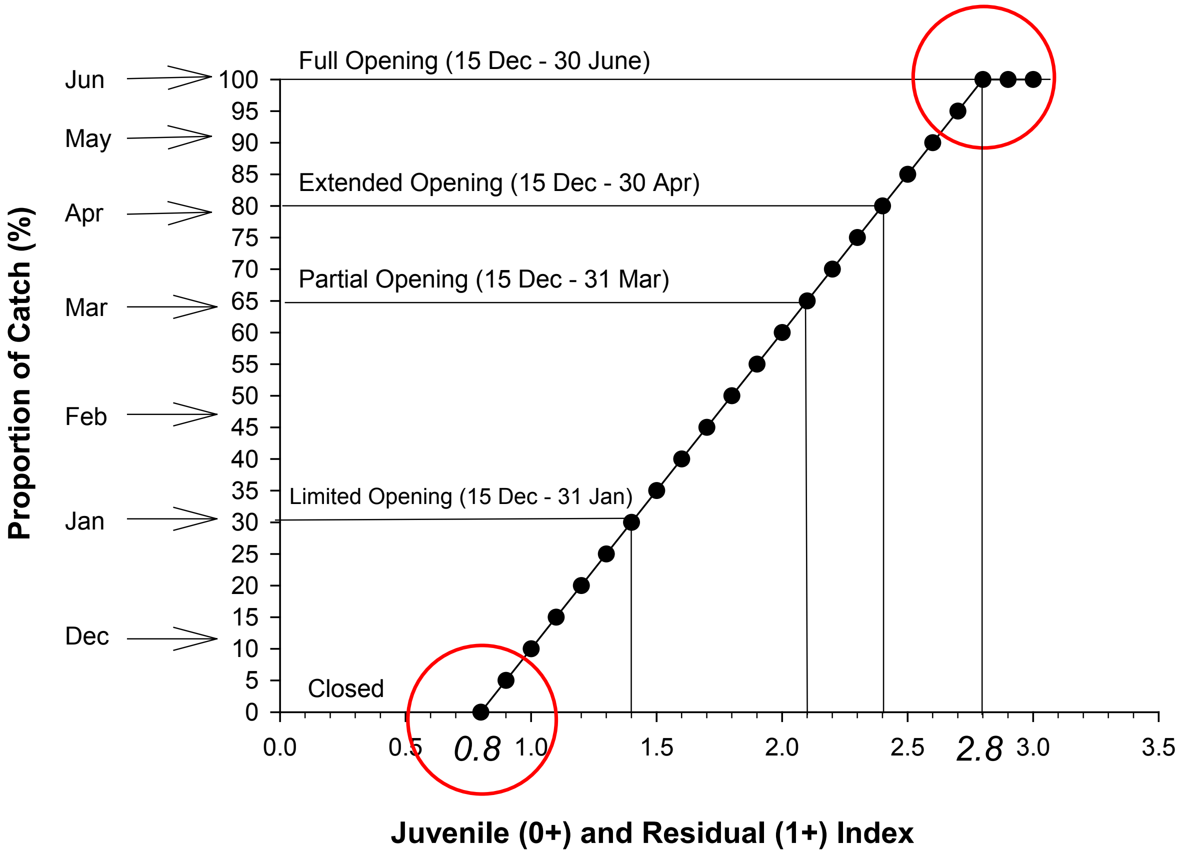

Figure 2.10. A draft decision-rule framework for the Cockburn Sound Crab Managed Fishery, which will assist in the management of the annual commercial catch. The framework adjusts the length of the commercial season according to a juvenile and residual index derived from monthly trawl surveys and commercial monitoring.

Calculation of the juvenile residual index and catch prediction model and its impact on the Decision-Rule Framework has been updated in the stock status chapter of this report (see Chapter 5).

2.5 Discussion

2.5.1 Factors Contributing to Collapse

The historically large fluctuations in commercial blue swimmer catches in Cockburn Sound have previously been attributed to changes in commercial fishing practices, normal variations in recruitment and natural mortality (Bellchambers *et al.*, 2006). However, since 2002/03 commercial and recreational catches have declined significantly, resulting in closure of the fishery in December 2006. The fishery has remained closed with predicted catches, based on juvenile recruitment indices, below historic levels. This paper demonstrates that using a minimum legal size for both the commercial and recreational crab fishery set well above size at sexual maturity and limited entry was not adequate for managing this fishery sustainably. The resultant collapse of the blue swimmer crab fishery in Cockburn Sound can be attributed to a combination of factors related to the biology and distribution of this species, fishery-dependent influences and environmental conditions.

2.5.2 Fishery near edge of species distribution – vulnerable to environmental fluctuations

Portunus armatus is a tropical species, with a wide distribution in Western Australia ranging between latitudes 20-34° South. The temperate waters of Cockburn Sound (~ 32°S) are towards the southern extreme of its distribution and consequently *P. armatus* is highly vulnerable to environmental fluctuations in this, and other southern fisheries, of Western Australia. More specifically the spawning period of blue swimmer crabs in these southern waters is limited to spring/summer whereas in more tropical waters such as Shark Bay spawning occurs year round, hence increasing spawning and recruitment potential (de Lestang 2003b). A strong correlation has been found between water temperature and recruitment success, with poor recruitment resulting from years where lower than average water temperature were reported in the months of August and September prior to spawning (de Lestang et al., 2010). This scenario occurred in four consecutive years between 2002 and 2005 where temperatures ranged between 15.7°C and 16.3°C and below the average of 16.5°C for Cockburn Sound. This extended cooler pre-spawning period was an unusual occurrence and an important contributing factor in the decline of the Cockburn Sound crab fishery. Conversely, when August and September water temperatures were above average such as in 1998 (17.3°C) and 2001 (17.0°C), good recruitment occurred the following year. Furthermore, while water temperatures encountered by developing larvae in Cockburn Sound influence larval survival and subsequent recruitment success, the timing of spawning has also been found to significantly influence recruitment success, with early spawning (August/September) years having increased recruitment success (de Lestang et al., 2010).

Such variations in temperature and recruitment success have often been linked with subsequent large variations in catches in many commercial decapod fisheries (Perry et al., 1995; Zheng and Kruse, 1999). A similar trend is evident in other blue swimmer crab populations on the edge of their species distribution such as the South Australian fishery where it has been predicted that post-larval settlement would be greatest in years with abnormally warm summers (Bryars and Havenhand, 2006). It also partially explained the large historical variations in blue swimmer crab catches in the Cockburn Sound fishery. High levels of fishing pressure, coupled with four years of reduced recruitment due to lower than average water temperatures in pre-spawning months, resulted in a significant reduction in the levels of egg production in this fishery (de Lestang et al., 2010). This reduction occurred after 2003/04 and catch levels remained low until closure of the fishery in 2006. So the combination of vulnerability to temperature fluctuations on account of its temperate environment, coupled with high fishing pressure over 4 consecutive cooler years resulted in recruitment overfishing of this species.

This decline parallels that of the blue crab fishery (*Callinectes sapidus*) of Chesapeake Bay, (Lipcius and Stockhausen, 2002) which suffered a poor recruitment in 1991, possibly due to environmental conditions as spawning stock was high. Heavy fishing pressure subsequently led to reduced spawning stock in 1992 and thereafter. More recent assessments confirm that decline in the blue crab fishery due to sustained fishing mortality and habitat degradation that has led to ~ 70% decline in blue crab abundance, 84 % decline in its spawning stock and historically low levels of juvenile recruitment (Zohar *et al*., 2008; Hines *et al*., 2008). This reduction and close relationship between spawning stock and recruitment is evident in Cockburn Sound (de Lestang et al., 2010). However, the reduction in the size of males (Abbe, 2002) and size of females and mean size at maturity that occurred during the decline in Chesapeake Bay (Lipcius and Stockhausen, 2002) needs to be verified for the Cockburn Sound crab fishery. The key consequence of this diminished spawning stock and recruitment has been an increase in the probability of recruitment failure and reduced resilience to demographic and environmental stochasticity (Lipcius and Stockhausen, 2002). This situation occurred in Cockburn Sound where adverse environmental conditions (consecutive years of cooler than average water temperatures) resulted in lower recruitment and continued heavy fishing resulted in very low spawning stock levels and recruitment failure. It is believed this reduced resilience has been a key reason why spawning stock in Chesapeake Bay has not recovered despite increasingly restrictive management and reductions in fishing pressure (Aguilar et al., 2008). Concerns remain about the resilience of the blue crab stock, as well as blue swimmer crab stock in Cockburn Sound, to natural perturbations and high levels of harvest as both are tropical species and at the latitudinal limit of their geographic range. In particular, blue crabs, suffer over-wintering mortality, the risk of which is highest for mature post-copulatory females which therefore require increased protection from fishing at this time (Aguilar *et al*., 2008).

Like the Cockburn Sound blue swimmer crab fishery, management of the California abalone fisheries also relied on a size limit large enough that the animals would reproduce several times before entering the fishery and this was considered adequate to protect stocks based on their high fecundity (Tegner et al., 2001). Size limits were assumed to allow healthy egg production even at high fishing mortality rates. However these assumptions did not consider extended periods of poor environmental conditions leading to extended recruitment failure. This clearly demonstrates that species vulnerable to environmental variations need further management measures in addition to size limits to protect breeding stock and ensure successful recruitment.

2.5.3 Self-recruiting population

Chesapeake Bay blue crabs undertake long-distance migrations over multiple habitats with larval migration from the Atlantic Ocean into upper reaches of the bay and rivers and migration of juveniles and subadults out of the tributaries to spawn in the lower deeper areas of the bay (Hines et al., 2008, Aguilar et al., 2008). By contrast, blue swimmer crabs in Cockburn Sound are a self-recruiting population with little immigration into, or emigration out of, the fishery from neighbouring water bodies. Genetic studies have confirmed that the population of blue swimmer crabs is generally independent from other stocks in the state (Chaplin et al., 2001) and although neighbouring crab populations in Swan River and Warnbro Sound are genetically similar to those in Cockburn Sound, little mixing occurs (Chaplin and Sezmis, 2008). Chaplin et al. (2001) warned that adverse changes in environmental conditions or high levels of fishing pressure could have highly detrimental long-term effects on the population.

2.5.4 Change in fishing method – increased fishing pressure on pre-spawning females

Conversion from gill nets to traps in 1994/95 clearly increased the commercial catch of blue swimmer crabs in Cockburn Sound, which peaked at 362 t in 1997. This dramatic increase was due to an over-estimate of the net to trap conversion factor (100 traps:1200 m set net) and resultant over-allocation of traps within the fishery. Recalculation of the conversion factor to 67 traps: 1200 m set net and a significant reduction in traps (Melville-Smith *et al*., 1999), resulted in what was believed to be a return to historical levels and stabilised CPUE. However, it is now apparent that although a recalculation of the net to trap conversion factor reduced the number of traps in the fishery from 1600 to 800 (Melville-Smith *et al*., 1999), the reduction in effort was not enough with levels of catch unsustainable in the long term, particularly during sustained periods of low recruitment. More importantly, conversion to traps resulted in a dramatic increase in catch and effort during the winter months (April-September) where catches were predominantly mated pre-spawning females, compared with gill net catches which were lower in winter due to lower fishing effort and lower catchability (Figs 2.3 and 2.4). This reduced the potential future egg production within the fishery to mainly one age class by effectively targeting the breeding females over winter, prior to spawning. This had not been the case previously as the majority of gill net fishing occurred over summer with very little effort occurring in winter. This increased heavy fishing pressure on pre-spawning females continued during the four consecutive years of below-average water temperatures and subsequent poor recruitment (2003/04, 2004/05, 2005/06), resulting in low breeding stock levels. Unfortunately, the introduction of a spawning closure in October and November in 1999 and prohibition on berried females did little to protect the breeding stock, which were being targeted during the months prior to extrusion of eggs.

Western Australian tiger prawn (*Penaeus esculentus*) stocks in Exmouth Gulf (Penn and Caputi, 1986) and Shark Bay (Caputi *et al*., 1998) have experienced similar stock collapses on account of recruitment overfishing. Both stocks are at the edge of their species distributions with restricted spawning periods and fluctuations in abundance due to environmental conditions. Like Cockburn Sound, life cycles were all contained within embayments and vulnerable to fishing once recruited onto available fishing grounds. Although no change in fishing method occurred in the prawn fisheries, the fishing power of the vessels increased significantly and the introduction of prawn-peeling machines enabled prawns to be targeted earlier in the season at a much smaller size. The tiger prawn stocks had two additional factors that contributed to their overfishing that did not occur in the crab fishery. The tiger prawns were driven to a low level on account of higher abundances of king prawns on the same grounds, and the targeting of prawns prior to spawning, whereas crab stocks are targeted after the first year class has completed spawning.

2.5.5 Juvenile Index

During the development of a juvenile index Bellchambers et al. (2006) used 0+ juveniles from both sexes in the middle and northern regions of Cockburn Sound to derive the most accurate index for predicting the following season's commercial catch. This was supported by reports that juvenile crabs were first found in the southern nearshore areas and at ~ 50 mm CW these juveniles moved into deeper southern offshore waters, then flowed into middle and northern regions of the embayment (Potter et al., 2001). Following the collapse of the fishery, a longer time series of data and additional recruitment sites allowed a refinement of the juvenile index which showed that the use of a greater number of recruitment sites more accurately re-created subsequent recruitment trends in the fishery. The decline in recruitment is clearly shown with highest recruitment indices immediately following conversion to traps in the late 1990s, followed by a steady decline in recruitment with lowest index in 2006, the year the fishery closed (Fig. 2.6). These trends are supported by declines in the mean catch rates of male and female crabs and numbers of juvenile crabs over the same time period (Fig. 2.7).

The abundance of juvenile blue crabs (*Callinectes sapidus*) has also been used successfully to measure recruitment in Delaware Bay (Kahn et al., 1998) and Chesapeake Bay (Lipcius and van Engel, 1990; Lipcius and Stockhausen, 2002) and the juvenile tanner crab abundance was used for Eastern Bering Sea (Zheng et al., 1998). Although these studies did not use these models to predict subsequent catch, larval, post larval or juvenile settlement indices have proved useful in forecasting abundance of decapod crustaceans. For example, in the Western Australian rock lobster (*Panulirus cygnus*) fishery, catches are accurately predicted 3–4 years in advance, based on the densities of post-larval lobsters (puerulus) (Caputi et al., 1995).

Given that the Cockburn Sound crab fishery is now closed, the current juvenile and residual index catch prediction model is an important management tool for assessing the recovery of stocks and ultimately predicting potential commercial catch when the fishery re-opens. The assessment undertaken in this study has shown that the most accurate catch prediction estimate has been derived from both the 0+ and 1+ components of the population (Fig. 2.8). This is due to the very large 1+ cohort that will contribute significantly to commercial catch once the fishery re-opens. Using only 0+ in the model would presumably underestimate the potential catch. Had the fishery operated in the 2007, 2008 or 2009 seasons, predicted catch would have been 77 t, 113 t and 156 t, respectively. These catch levels were below acceptable levels and the fishery has remained closed.

2.5.6 Recovery

The recovery of the Cockburn Sound crab fishery has been relatively slow with only minor increases in recruitment over the three years, 2006-2008 (Figs 2.6, 2.7). Spatial differences in the rate of recovery of juvenile abundance are evident, with higher numbers of juveniles in Mangles Bay and Jervois Bay, whereas areas of CBH jetty and Colpoys Point have had minimal recovery. These spatial variations in recruitment are most likely attributed to the higher coverage of seagrass beds in nursery areas, such as Mangles Bay and Jervois Bay (Kendrick *et al*., 2002) and validate the inclusion of multiple sites in the development of a juvenile index. A similarly slow rate of recovery has occurred for female abundance, with numbers of female crabs/traplift only increasing after 2 years of closure in 2008 and numbers/m^2 increasing only incrementally between 2006 and 2008 (Fig. 2.6b, 2.6c). This slow recovery of juvenile and adult crab abundance is supported by historical trawl data where the total number of crabs.m^{-2} in 2008 remains considerably lower than years where trap fishing occurred and catches were reasonable. A change in the sex ratio pattern following closure has occurred where males now dominate the commercial catch for longer, until June, with females only becoming dominant from July through to November. This three-month lag in the dominance of females is explained by higher numbers of males in traps, which would have previously been depleted by fishing during the summer.

This slow rate of recovery is surprising as blue swimmer crabs are a highly fecund short-lived species, and were thought to be capable of recovering quickly in the absence of commercial and recreational fishing. This was based on the strong stock-recruit relationship ($R^2 = 0.94$, $p<0.001$, $df = 9$) determined by de Lestang et al. (2010). It is possible that breeding stock levels had been fished to such low levels that despite warmer years in 2006 and 2007, recruitment has remained poor. Consequently the fishery has remained closed for three years.

2.5.7 Management

The management objectives of this fishery are to ensure that breeding stock is maintained above minimum levels determined from the stock-recruitment relationship and that there is a significant residual stock remaining. Future management arrangements for this fishery will limit the level of fishing effort in winter months to protect the mated pre-spawning females and provide a buffer to breeding stock. A permanent closure for July-August is under consideration for when the fishery reopens. Furthermore, as the ratio of males to females changes from predominantly males between January and March to females between April and September, fishing effort in the months where females dominate the catch will be minimised to increase overall egg production, particularly in years when water temperatures and resultant recruitment have been low. The decision-rule framework will be a valuable management tool for determining the appropriate amount of fishing in the Cockburn Sound crab fishery each season. Using the juvenile and residual index, the level of predicted catch to be fished by the commercial and recreational sectors, will be controlled by the length of fishing season, minimum size and effort (trap number) restrictions. The choice of the limit and threshold levels for the juvenile and residual abundance is based on historical levels and will be reviewed when the fishery is reopened and the effects of fishing on residual abundance and egg production are evaluated. This management strategy was chosen to alleviate fishing pressure on mated pre-spawning females, provide a buffer to spawning stock by allowing a proportion of residual stock to remain in the water and reduce the number of traps in what is considered to be a small fishery with an excess of gear and latent effort.

Alternative management arrangements have been implemented for recovering crab stocks in Chesapeake Bay in accordance with the greater complexity of its life cycle, long-distance larval, juvenile and sub-adult migrations, nursery habitat and recruitment depletion, variations in temperature and salinity throughout the geographic range of the fishery and multi-state management. These strategies include sanctuary zones to protect the spawning females and establishment of migration corridors to protect females when they undergo the long distance migration after mating to lower Bay spawning areas (Aguilar et al., 2008). The drastic depletion of blue crab seed stock resulted in a continuous decline of juvenile abundance in nursery habitats along tributaries of Chesapeake Bay (Lipcius *et al*., 2003) and has also made the blue crab an excellent candidate for restocking. The aim of this program is to recover spawning biomass and in turn larval abundance and recruitment to restore the blue crab population (Zohar *et al*., 2008). Over-wintering mortality and variations in temperature and salinity and macro- and micro-habitat throughout the Bay make the timing and location of release crucial to successful restocking in the fishery (Aguilar *et al*., 2008; Hines *et al*., 2008; Zohar *et al*., 2008). The small spatial area of Cockburn Sound and absence of long-distance migrations into and out of estuaries suggests the migration corridors and sanctuary zones within Cockburn Sound would not be appropriate. A ban on winter fishing on post-copulatory pre-spawning females as well as the existing spawning closure in September and October effectively acts in a similar way to the migration corridors and sanctuary zones in Chesapeake Bay. However, stock enhancement into known nursery areas of Cockburn Sound could be a potentially useful tool if crab stocks do not recover fully under new management regimes as nursery areas are recognised and survival of released animals could be monitored effectively with the co-operation of the fishing industry.

At this stage the Cockburn Sound crab fishery will remain closed until breeding stock and recruitment have recovered – see Chapter 5 for current stock status and management arrangements. It is anticipated that the high productivity of these stocks should result in a full recovery, provided environmental conditions are favourable.

3.0 Stock-Recruitment-Environment Relationship

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3.1 Abstract

Blue swimmer crab (*Portunus armatus*) fisheries in Western Australia have generally been considered robust to recruitment overfishing, as the minimum legal size for retention of these crabs in both the commercial and recreational crab fisheries are set well above the size at sexual maturity allowing crabs to spawn at least once before entering the fishery. However, the Cockburn Sound crab stock suffered a recruitment collapse, with three key factors: (a) the fishery is near the edge of this species distribution and hence vulnerable to environmental fluctuations; (b) a number of consecutive years of poor environmental conditions resulted in poor recruitments; and (c) high fishing pressure continued on these low recruitments. This study indicates that water temperatures at the start of the spawning season positively influence the strong stock-recruitment relationship for *P. armatus* in Cockburn Sound. Apparently, warm water temperatures at the onset of spawning result in the larger females producing additional broods of eggs, and therefore a far greater number of larvae over the short spawning season. This relationship produces catch predictions for this fishery a year ahead and provides information for the development of biological reference points for management.

3.2 Introduction

Large inter-annual variations in population size are common amongst crustaceans (Lipcius and Van Engel 1990; Metcalf et al. 1995; Wahle et al. 2004). For those species that support fisheries, variation in population size is typically reflected in significant fluctuations in landings, which create uncertainty for managers and may consequently have an adverse effect on the livelihoods of commercial fishers (Zheng and Kruse 1999; Bellchambers et al. 2006).

Year-to-year variations in stock size are largely attributed to variations in recruitment (both larval and the emigration of adults) and fishing mortality (the removal of older larger animals) (Ricker 1954; Beverton and Holt 1957). Although successful larval recruitment is reliant on adequate spawning biomass, the strength of this is usually influenced by various physical or biotic factors affecting the survivorship of both larval and juvenile stages prior to and after settlement (Cobb and Caddy 1989; Wahle 2003). For example, successful settlement of western rock lobster (*Panulirus cygnus*) puerulus along the coast of Western Australia is dependent on climatic conditions such as warm water temperatures, which influence growth/survival, and winds favourable to the transport of larvae towards the coast prior to settlement (Caputi et al. 2001).

Other environmental variables demonstrated to affect the survivorship and recruitment of decapods include water temperature (McConaugha et al. 1983), salinity (Anger et al. 1998), turbidity (Penn and Caputi 1986), habitat availability (Botero and Atema 1982) and oceanographic processes, including tidal velocities and prevailing currents (Goodrich et al. 1989; Caputi et al. 1995; Rabalais et al. 1995; Lee et al. 2004; Queiroga et al. 2006). Although recruitment may be influenced by any one of these environmental variables, the ability to model the relationship, and the relevance of the relationship to the management of the fishery, will be dictated by the strength of the recruitment correlation (Walters and Collie 1988; Basson 1999).

Water temperature has been implicated as an important factor in the majority of the recruitment-environment relationships and is often robust enough to persist over substantial time frames (Caputi et al. 1995; Uphoff 1998). This is particularly true of stocks located near the latitudinal limit of species distributions, where water temperatures can be outside the optimal range for successful recruitment (Myers 1998). Water temperature may affect recruitment in a variety of ways. For example, elevated water temperatures typically have a positive effect on decapod recruitment by accelerating larval development and reducing the duration of the larval phase and larval mortality (Bryars and Havenhand 2006; Fisher 2006). Elevated water temperatures prior to spawning may also directly affect the timing of larval release by controlling gonad development, mating and the timing of spawning (Rosenkranz et al. 2001) as well as the larval habitat through changes to the abundances of larval foods and predators.

The blue swimmer crab *Portunus armatus* (A. Milne Edwards, 1861) is distributed throughout the shallow marine and estuarine waters of the Indo-Pacific. Although predominantly a tropical or sub-tropical species, *P. armatus* is also found as far south as the temperate waters of southern Australia and differing environments throughout its large latitudinal range (26º–34ºS) have a major influence on its reproductive biology. de Lestang et al. (2003a) demonstrated that the spawning season of *P. armatus* in Shark Bay, where water temperatures remain above 18ºC for a substantial part of the year, is considerably more protracted (spawns year round) than in the temperate waters of Cockburn Sound where the spawning season is restricted to spring and summer. They suggested that water temperatures have a significant influence on egg production in blue swimmer crabs, and therefore the timing and longevity of the spawning period. Additionally, in the temperate waters of South Australia, Bryars and Havenhand (2006) demonstrated increased survivorship of *P. armatus* larvae at temperatures over 19ºC and concluded that post-larval settlement would be greatest during abnormally warm summers. This highlights the influence water temperature can have on the life cycle of these crabs. It can affect the timing of spawning, which influences egg release times and the environment into which the larvae are released. Water temperatures during the larval cycle dramatically influence the length of larval life and therefore survival and the timing of juvenile recruitment, which can then impact on the ability of juvenile crabs to mature and mate the following year (Yatsuzuka, 1962). Therefore, water temperatures during one part of the life cycle can significantly alter population size and structure over a far greater timeframe.

Cockburn Sound, situated 30 km southwest of Perth, Western Australia (WA), was the second largest of the four main blue swimmer crab fisheries in WA. Commercial catch of blue swimmer crabs from Cockburn Sound is characterised by high inter-annual variability, ranging between 84 and 362 t from 1989/90 to 2004/05. Cockburn Sound, which is close to the Perth metropolitan area, also supports an important recreational crab fishery. Recreational surveys in the last 10 years have indicated an annual catch of between 18 and 23 t. Although the variability in catch has been attributed to recruitment success (Bellchambers et al. 2006), the specific factors responsible for variation in recruitment strength were not identified.

Blue swimmer crab fisheries in Western Australia have generally been considered robust to recruitment overfishing as the minimum legal size for the Cockburn Sound fishery for both the commercial and recreational crab fishery (130 and 127 mm carapace width (CW), respectively) are set well above the size at sexual maturity (98 mm CW) allowing crabs to spawn at least once before entering the fishery (de Lestang et al. 2003). However, an extremely low catch (53 t) from high levels of effort in 2005/06, which signified high exploitation and the possibility of recruitment overfishing, prompted managers to close the Cockburn Sound fishery for three seasons (2006/07, 2007/08 and 2008/09). The impact a management response such as this can have on the livelihoods of fishers and recreational interests of fishers highlights the pressing need for understanding the cause of the recruitment decline and improved management of the fishery.

The aim of the present study was to determine the combination of spawning stock and environmental effects that contributed to the collapse of this seemingly robust stock to enable an assessment of whether other similar fisheries may also be vulnerable.

3.3 Methods

3.3.1 Standardized egg production index

An index of egg production (*EPI*) for Cockburn Sound was developed using data derived from the three sampling methods (small and large research survey trawls and commercial trap-based sampling). An index of egg production is the most appropriate measure of breeding stock abundance as it directly relates to the abundance of eggs/larvae produced by the stock. Measures such as female abundance fail to account for the non-linear relationship between crab size and eggs produced.

Each female crab captured during fishery-independent trawling and commercial crab-trap sampling was assigned a total potential egg production based on a batch frequency (*BFr*) to *CW* relationship ($BFr = 1 + 2/\left(1 + \exp\left(-\log\left(19\right)\left(CW - 113.7\right)/13.8\right)\right)$) and a batch fecundity (*BFe*) – *CW* ($\log BFe = 1.821 \log CW + 3.2862$) relationship (de Lestang et al. 2003a). For example, the above equations estimate a 100 mm CW female *P. armatus* will produce an average of 1.12 batches of eggs, each totalling 117 270 eggs in a spawning season, which equates to a total potential egg production of 129 230 eggs season^{-1}. This relationship was used to convert female catch rates (female crabs m^{-2} trawled or potlift^{-1}, depending on the survey method) into potential egg catch rates (eggs m^{-2} trawled or potlift^{-1}). A Generalised Linear Model (*GLM*) was then used to produce a seasonal (July – June) potential egg catch rate estimate (*EPI*) (a *GLM* was used to standardise for an unbalanced sampling design and sampling methodology). The samples were also restricted to water depths ≥ 15 m, since the majority of breeding-sized females are found in these water depths (Potter et al. 2001). The average egg production per sample (m^{-2} or trap^{-1}) was log transformed to remove skewness from the data (Clark and Warwick 2001). Method of capture (small and large research trawl and crab trap), season and month were treated as factors in the *GLM* with all two-way interactions. Back transformation of least-squares means of the seasonal estimates were used as the standardized *EPI*.

3.3.2 Water temperature

The monthly water temperature data incorporated into the stock-recruitment relationship was recorded at Warnbro Sound (10 km south-west of Cockburn Sound) as part of a survey of western rock lobster *Panulirus cygnus* recruitment conducted since 1984. Two replicate water temperature measurements were collected monthly using a mercury thermometer from a boat in a standard location towards the centre of the Cockburn Sound embayment at a depth of about 2 m. For the few years when measurements are available from both locations, Warnbro Sound water temperature were found to be very similar to those experienced by crabs in Cockburn Sound ($r^2 = 0.86$, $P<0.001$, d.f.=31, data not shown).

3.3.3 Stock-recruitment relationship

A modified Beverton and Holt (1957) stock-recruitment equation, $Catch = \left(EPI \times \exp\left(Wtemp \times -a\right)\right) / \left(b + c \times EPI\right)$, was used to describe the relationship between spawning stock ($EPI_{t/t+1}$), subsequent recruitment strength (commercial catch $_{t+1/t+2}$) and water temperatures (*Wtemp*) just before, during and after peak egg production, i.e. May_t to $April_{t+1}$. Commercial catch was used as a proxy for recruitment strength since the seasonal commercial catch (December to September) is mainly derived from a single 1+ year class (de Lestang et al. 2003b; Bellchambers et al. 2006). Although CPUE in the Cockburn Sound commercial blue swimmer crab fishery has followed similar patterns to total landings during recent years, the use of annual landings as a measure of crab abundance was considered more appropriate than CPUE. This is because the fishery underwent major gear and effort changes in the early 1990s, and as such a consistent CPUE measure cannot be determined. Commercial catch on the other hand was considered a good proxy of settlement one year previously, since the legal population (mainly 1 year-old crabs) are substantially depleted each fishing season to the point that fishing becomes no longer economic viable.

The relationship between spawning stock, recruitment and water temperature in months before, during and after peak egg production (and combinations of these months) was examined and the resultant r^2 values were examined to determine which of the monthly water temperatures (or combinations of months) have the strongest relationship with egg production and catch.

3.4 Results

The mean monthly water temperature cycle in Warnbro Sound (between 1996 and 2008) was lowest (16.1ºC) in August, after which water temperature rose through spring and early summer to a maximum of 23.6ºC in January (Fig. 3.1a). The mean percentage of female *Portunus armatus* that were ovigerous in any month demonstrates that the majority of reproductive activity in Cockburn Sound occurs during spring and summer, with the mean percentage of ovigerous crabs peaking in October and remaining high (>40%) until January (Fig. 3.1b).

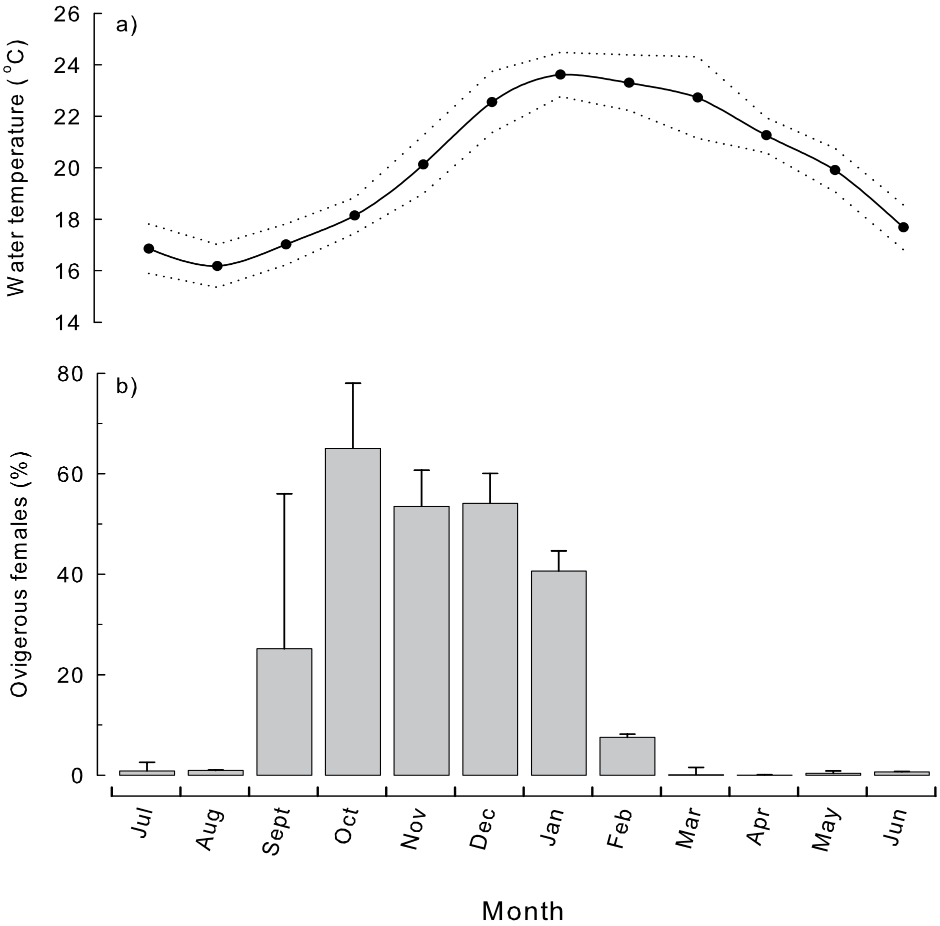


Fig. 3.1. a) Mean monthly water temperatures (solid line) (±1SD, dotted lines) from Warnbro Sound between 1996 and 2008. b) Mean monthly percentage (+1SD) of ovigerous female *Portunus armatus* among all adult female *P. armatus* collected in Cockburn Sound from depths >15 m. Means are collated from research trawl samples and commercial catch monitoring data.

Although the annual egg production index (*EPI*), which is a proxy for the size of the spawning stock each year, and the recruitment to the fishery (commercial catch) each season have both shown a general decline over the study period, fluctuations in *EPI* values alone explain little of the annual variation in subsequent commercial catches ($r^2 = 0.36$, $P = 0.05$, d.f.=9). The incorporation of water temperatures from individual months during the early – mid spawning season into the stock-recruitment relationship (SRR) increased the fit of the model substantially. The best fit explained approximately 76% of the variation in the catches and was produced by using August water temperatures in the model (Fig. 3.2), although good fits were generally obtained for months, August to December. In addition to the individual months, average water temperatures for various combinations of months from August to December were also evaluated in the SRR. The r^2 derived from the SRR of the mean water temperature during each of the combinations of months tested was greater than for that of August alone (Fig. 3.2) and the best correlation ($r^2 = 0.94$, $P < 0.001$, d.f.=9) was derived from using the average water temperature in August and September during the commencement of spawning (Fig. 3.3). The relationship between water temperature in individual months (and an average of months) and commercial catch without incorporating EPI in the model was also examined and the best relationship was not statistically significant ($r^2 = 0.26$, $P = 0.09$, d.f.=9).

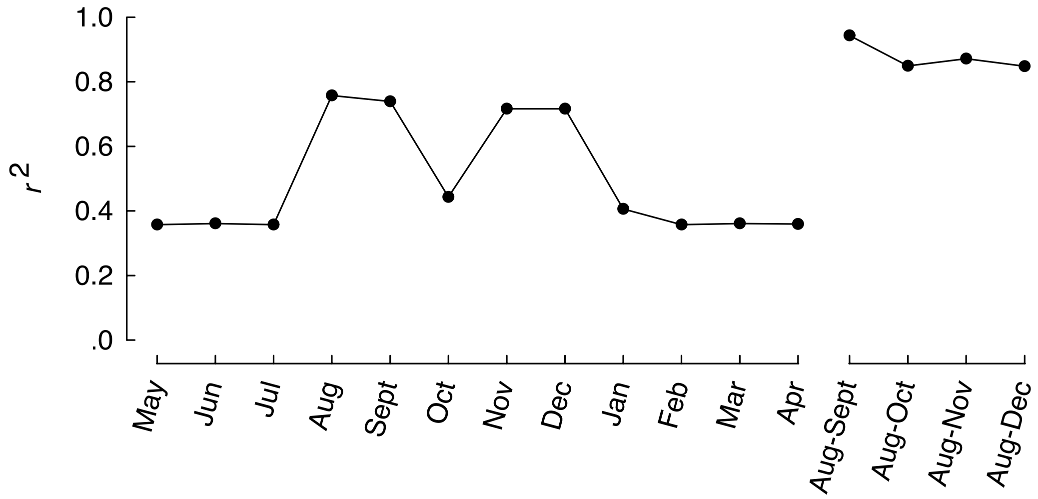


Fig. 3.2. Coefficient of determination (r^2) between observed stock (egg production index) and recruitment (commercial catch) and the fitted the Beverton and Holt stock-recruitment relationship, using egg production and the commercial catch (recruitment) of the following year, and the water temperatures in different months, or combinations of months, near the spawning and larval period.

The strong influence of water temperature on the successful recruitment of crabs is demonstrated during the last decade, as the fishing seasons in which commercial landings were largest, i.e. 1997/98 and 1999/00, followed years, 1996 and 1998, respectively, in which August/September water temperatures were elevated (>17 ºC) and the levels of egg production were moderate (Fig. 3.3). In contrast, when the mean August/September water temperatures were <16ºC, e.g. 2003 and 2004, subsequent commercial landings in 2004/05 and 2005/06, respectively, were reduced, irrespective of the degree of egg production in the previous year (Fig. 3.3). Historically, the mean August/September water temperature in Warnbro Sound has fluctuated around the long-term average of 16.6 ºC, reaching a low of 15.7 ºC and a high of 17.7 ºC (Fig. 3.4). However, in recent years (2002–2005), mean August/September water temperatures remained below the long-term average for four consecutive years.

The initial reduction in catch in 2003/04 and 2004/05 appears to be mainly due to the environmental conditions (low water temperatures in 2002 and 2003), as the spawning stocks in the previous years (2002/03 and 2003/04) were at moderate levels (Fig. 3.3). The low recruitment to the fishery in these years, combined with fishing pressure, resulted in low levels of egg production in 2004/05. The subsequent low catch observed in 2005/06 along with the predicted low catches for 2006/07, 2007/08 and 2008/09 (based on juvenile abundance) may be due to the effect of low egg production.

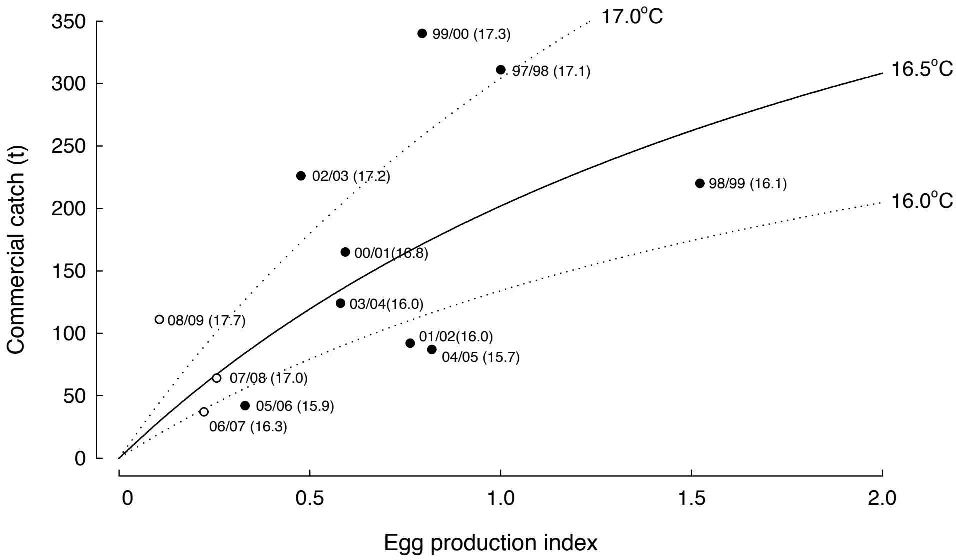


Fig. 3.3. Beverton and Holt stock-recruitment relationship between commercial catch and egg production (preceding season) at three different water temperatures (mean August/September), i.e. 16.0, 16.5 and 17.0ºC. The year (fishing season) and the mean temperature during the preceding August and September (in parentheses) are indicated. Open circles represent estimated commercial catches for the 2006/07, 2007/08 and 2008/09 seasons based on recruit-catch relationship developed by Johnston et al. (2011).

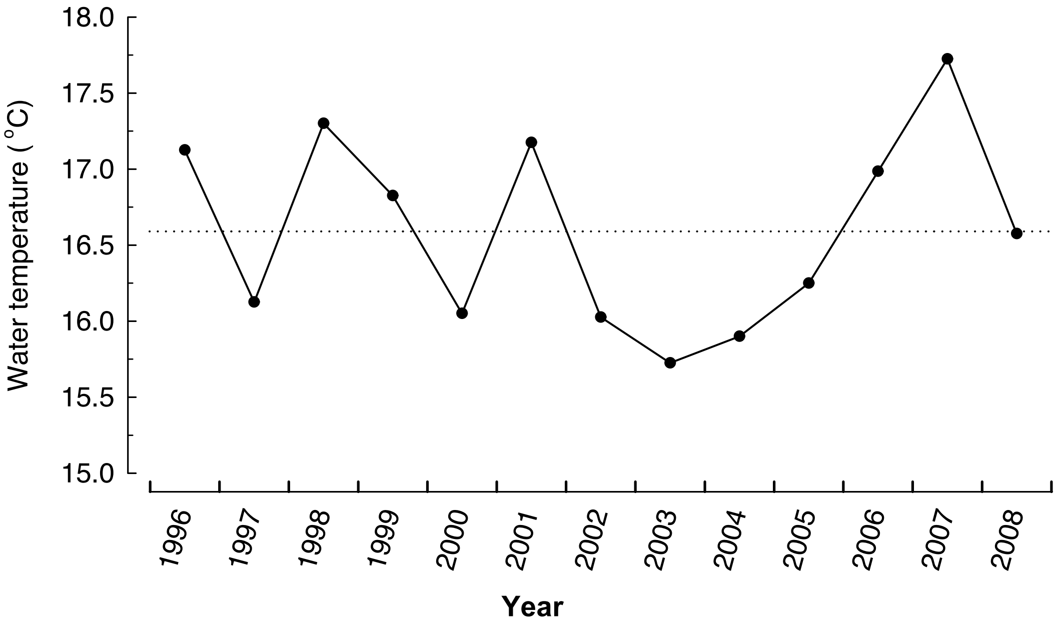


Fig. 3.4. Mean water temperatures (solid line) for August-September recorded in Warnbro Sound for the period 1996 to 2008. The average August-September water temperature (16.6ºC) for the entire period is also indicated (dotted line).

The proportion of female crabs that are ovigerous in each month exhibit a similar annual pattern, increasing rapidly from a very low proportion in July and August to a peak two months later of between 0.5–0.9 in October (Fig. 3.5). Proportions remain high through until January and then decline to essentially zero from March to June. Although this pattern remains similar between years, the magnitude of the proportions in a given month differ markedly following either a warm (>16.9 ºC) or cool (<16.3 ºC) mean August/September water temperature period (> or < 0.3ºC of the long term average 16.6ºC). The most marked example of this is shown by the multiple spawning females (CW >115 mm, see de Lestang et al. 2003a), with their proportions of ovigerous females being far greater (in some cases double) following a warm than cool August/September period (Fig. 3.3).

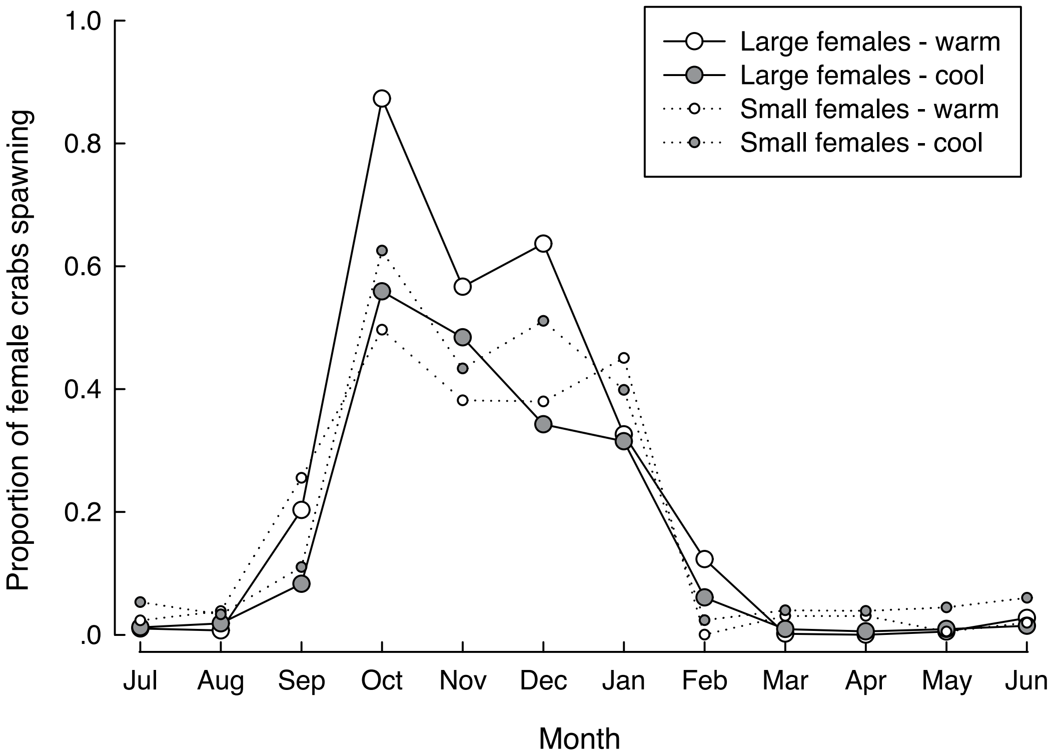


Fig. 3.5. Variation in the monthly proportions of small (CW 85 – 115 mm) and mainly single-brood producing females and large (CW ≥ 115 mm) mainly multiple-brood producing females following warm (>16.7ºC) and cool (<16.1ºC) August-September periods.

3.5 Discussion

We have demonstrated the importance of including environmental conditions (temperature) in the development of the SRR for *P. armatus* in Cockburn Sound. Stock size alone, indexed by the EPI, explained a small proportion of the variance in recruitment (r2 = 0.36). Similarly water temperature alone (r^2 = 0.26) was insufficient to explain recruitment. The poor recruitments, which occurred from 2004–2006, appears to be the result of high level of exploitation (Johnston et al, 2010) on a series of low recruitments that initially occurred due to poor environmental conditions. There is a strong correlation between water temperatures and recruitment success of blue swimmer crab *Portunus armatus* in Cockburn Sound, after taking into account the effect of the breeding stock. The marked influence of water temperatures on crab recruitment is not unexpected considering the tropical affinities of *P. armatus* and location of Cockburn Sound in the temperate waters of Western Australia. Bryars and Havenhand (2006) demonstrated that water temperature has an important influence on *P. armatus* larval duration and survival and predicted that post-larval settlement in the temperate waters of South Australia would be greatest during abnormally warm summers.

While water temperatures encountered by developing larvae in Cockburn Sound may influence larval survival and subsequent recruitment success, analysis of the r^2 values from the model demonstrate that water temperatures between August and December, i.e. at the beginning and during the spawning period, are more indicative of successful crab recruitment in the following year. This relationship suggests that recruitment success depends on a relationship between water temperature and the timing/magnitude of spawning.

The timing of spawning (more eggs released earlier) may contribute to strong recruitment in a number of ways. For example, early spawning may result in larvae being released at a time that allows them to take advantage of the particular food resources available at that time (e.g. Fisher 2006). It may also allow the larvae and subsequent juveniles more time in the warmer waters of spring/summer to grow faster and spend less time in small size classes that are most vulnerable to mortality (i.e. predation).

In addition, an early start to spawning or a greater proportion of mature females spawning at the beginning of the spawning season may lead to an increase in the total number of juvenile crabs produced by providing female crabs the opportunity to produce, incubate and hatch their maximum number (three) of egg batches (de Lestang et al. 2003a). Without prolonged periods of favourable conditions it is unlikely that female crabs will mature early enough, reach an adequate size or have sufficient time to hatch this many batches of eggs. The far greater proportion of large ovigerous females following a warm rather than a cool August/September indicates that these females carried an extra batch of eggs in these years, which supports the above scenario.

The apparent role of high fishing pressure during periods of low recruitment brings into question the assumption that blue swimmer crab fisheries in Western Australia are robust to recruitment overfishing. It appears that high levels of fishing pressure, coupled with three years of reduced recruitment due to unfavourable environmental conditions, resulted in a significant reduction in the levels of egg production (Fig. 3.3). This reduction is evident after 2003/04 and these levels have remained low in subsequent years. High exploitation rates were exacerbated by a shift by commercial fishers in 1993/94 from set nets to crab traps coincided with a marked increase in average total crab landings by the late 1990s (Johnston et al. 2011). The shift to crab traps resulted in an increase in the winter catch where there was high proportion of females caught. These females would have participated in their second year of spawning and their removal would have exacerbated the rate of decline in the EPI during periods of low recruitment.

Cockburn Sound is certainly not the first crab fishery thought erroneously to be resilient to overfishing. Chesapeake Bay blue crab fishery, once the most productive estuarine system in America, continues to report lower harvests each season since catches peaked in the early 1990s. This decline in catch is considered to be due to a combination of overfishing and adverse water quality and environmental conditions (Bunnell and Miller, 2005, Lambert et. al., 2006a, b).

The SRR with environmental effects incorporated needs to be further tested as the time series of stock and recruitment data used to generate the relationship in this study is relatively short (only nine years). The key test should occur in the next few years as the fishery recovers. The time period for the recovery for this short-lived species is expected to be relatively fast (e.g. 3–4 years) especially with the favourable water temperatures recorded for 2006 and 2007. The recruitment-environment relationship also needs to be verified as there are large numbers of environmental conditions that can be tested in space and time, which raises the risk of spurious correlations (Walters and Collie 1988). In the present study the water temperature time series at the nearest location near the spawning and larval period was the only variable tested as it was considered the key indicator likely to influence the crab stock.

The stock-recruitment-environment relationship produced during this study allows catch predictions to be made for the Cockburn Sound crab fishery a year in advance. This forecasting capacity can be verified by the abundance of juvenile crabs sampled in March – August (Bellchambers et al. 2006; Johnston et al. 2011), reduces uncertainty for fisheries managers and enhances their ability to make reliable management decisions. The early implementation of informed management actions significantly aids in the sustainable management of this fishery.

The development of an egg production index for Cockburn Sound provides managers with a baseline against which the level of *P. armatus* breeding stock can be assessed. However, these results demonstrate that, even at adequate levels of egg production, year to year variability in environmental conditions have a large influence on *P. armatus* recruitment. This variability is important to the resilience of the fishery and needs to be accounted for when developing robust biological trigger points (Johnston et al., 2011). This model, which quantifies the influence of water temperature on crab recruitment, will aid in the management of the fishery.

It is worth considering the combination of factors that have contributed to the collapse of this seemingly robust stock to enable an assessment of whether other similar fisheries may also be vulnerable. For the Cockburn Sound crab stock the key factors were: (a) the fishery is near the edge of this species distribution and hence vulnerable to environmental fluctuations; (b) a number of consecutive years of poor environmental conditions resulted in poor recruitments; and (c) high fishing pressure continued to be applied to the stocks.

There have been two other crustacean fisheries where recruitment overfishing has occurred in Western Australia in the 1980's – the tiger prawn (*Penaeus esculentus*) stocks in Exmouth Gulf and Shark Bay (Penn and Caputi 1986; Caputi et al. 1998). There are a number of similarities with the crab collapse as the tiger prawn was also near the edge of its distribution with a restricted spawning period compared to other prawn stocks in the region and subject to large fluctuations in abundance due to environmental conditions. Its life cycle was also contained within embayments with the spawning stock aggregating in the deep water and hence vulnerable to fishing throughout the life cycle. While there was no change in fishing method associated with these fisheries, there were significant increases in fishing power of the vessels and the introduction of prawn peeling machines that enabled the prawns to be targeted earlier in the season at a much smaller size. The tiger prawn stocks had two additional factors that contributed to their overfishing that do not occur in the crab fishery. The multi-species nature of the prawn fishery resulted in the tiger prawn stocks being fished at low abundance level because of the good abundance of the king prawn stocks. Secondly, the tiger prawn stocks were fished for a number of months before spawning commenced whereas the crab stocks are fished after the first spawning of the year class is completed.

While the stock -recruitment-environment relationship produced during this study is unique to *Portunus armatus* in Cockburn Sound, the factors contributing to the collapse are directly relevant to other highly exploited fisheries, particularly those whose catches are based on a single age class, e.g. blue crab in Chesapeake Bay, and stocks are near the limit of their species distribution eg. South Australian blue swimmer crab stocks and Florida spiny lobsters (*Panulirus argus*).

4.0 Warnbro Sound and Swan River Crab Fisheries

4.1 Genetic study

The first objective of this aspect of the study was to:

Determine whether crabs in Swan River, Warnbro Sound and Cockburn Sound are the same population (through genetic microsatellite analysis) to assess if separate management measures need to be implemented for each population.

This objective was subcontracted to Jenny Chaplin (Murdoch University) and the key results are summarised below from their executive summary with further details available from Chaplin and Sezmis (2008).

This study provides a genetic assessment of the relationships among the assemblages of the blue swimmer crab *Portunus armatus* in Cockburn Sound, the adjacent Swan River Estuary and near-by Warnbro Sound in south-western Australia. It was commissioned by the Department of Fisheries Western Australia in view of recent declines in the catch rate and recruitment in this species in Cockburn Sound.

The assessment was based upon the patterns of variation at four polymorphic microsatellite loci in samples of *P. armatus* collected from Cockburn Sound, the Swan River Estuary and Warnbro Sound in 2007 and 2008.

The results indicate that the genetic compositions of the assemblages of *P. armatus* in Cockburn Sound, the Swan River Estuary and Warnbro Sound were homogeneous at the time of sampling (2007/2008) and thus that *P. armatus* is represented by either a single biological stock, or a series of overlapping stocks, in these water bodies. It is not possible to use the genetic data of this study to distinguish between these alternatives (single versus overlapping stocks) because only small or occasional amounts of gene flow are required to homogenise the genetic compositions of different sub-units of a species.

On the basis of all of the available information, we have tentatively concluded that the amount of gene exchange between the assemblage of *P. armatus* in Cockburn Sound and those in the Swan River Estuary and Warnbro Sound is temporally variable and generally insufficient to have major impact on the abundance of this species in any of these water bodies, *i.e.,* that *P. armatus* is represented by a series of overlapping stocks (rather than a single stock) in these water bodies. This information consists of a simplistic assessment of the distribution of barriers to dispersal in *P. armatus* in south-western Australia and a combination of the genetic results of the present study and those of a previous study by Sezmiș (2004), which was based on samples of *P. armatus* collected from a range of water bodies, including Cockburn Sound, the Peel-Harvey Estuary and Geographe Bay in south-western Australia (but not the Swan River Estuary and Warnbro Sound) in 1999 and 2000.

In conclusion, the assemblages of *P. armatus* in Cockburn Sound, the Swan River Estuary and Warnbro Sound were not genetically differentiated from each other at the time of sampling and probably comprise a series of overlapping biological stocks, although we cannot exclude the possibility that they are all part of the same biological stock.

4.1.1 Management Implications

The results of this study indicate that the genetic compositions of the assemblages of *P. armatus* in Cockburn Sound, the Swan River Estuary and Warnbro Sound were homogeneous at the time of sampling (2007/2008). This finding suggests that there is some gene exchange (and hence dispersal) in *P. armatus* among these water bodies, although it was not possible to quantify the amount of such. However, it is likely that the amount of gene exchange between the assemblage of this species in Cockburn Sound and those in the Swan River Estuary and Warnbro Sound is temporally variable and generally insufficient to have major impact on the abundance of this species in any of these water bodies. In fact, on the basis of (simplistic) deductions about the distribution of likely barriers to dispersal in this species in these waters, we predict that the assemblage of *P. armatus* in Warnbro Sound is more strongly connected to those in the Peel-Harvey Estuary and other sites in south-western Australia than to Cockburn Sound. Consequently, management of south-western crab fisheries will need to be considered in light of the close relationship between populations.

4.2 Commercial monitoring

The second objective was to:

Determine the length frequency, sex ratio and proportion of berried females in Swan River and Warnbro Sound to assess the population status in each fishery (recruits and spawning stock).

4.2.1 Methods

Study sites

The Swan-Canning river system (32° 0'S, 115° 50'E) runs from the coast at Fremantle, Western Australia, through the centre of Perth, and inland for 67 km where it becomes the Avon River (Fig. 1.1). The estuary and its catchment have been highly modified since European settlement in 1829, resulting in widespread losses of aquatic habitat, the input of contaminants and reduced freshwater flows. The lower reaches of the Swan River are relatively wide and deep, with the enlargement of the river mouth in 1895 allowing sufficient marine water to enter the river system such that the lower reaches of the Swan and Canning River (up to the Kent Street Weir) constitute an estuary. The upper reaches of the Swan River are classified meso- to eutrophic, and consist of long, shallow stretches of river channel (1–3 m deep) that are punctuated by deeper (4–5 m) sections. The estuary is subject to a microtidal regime, with a maximum tidal amplitude of about one metre, although water levels are also subject to barometric pressure fluctuations.

Warnbro Sound is a small (area ~ 50 km^2), micro-tidal coastal basin located 30 km south of Fremantle (32° 20'S, 115° 43'E) (Fig 1.1). It is approximately 7 km long and 4 km wide and consists of three main sectors: a central deep basin (average depth ~ 17 m) with a relatively flat bottom of fine organic mud; and two extensive banks, the north (depth range ~ 1-4 m) and south (depth range ~ 1-9 m) sand platforms, which contain deposits of clean sands colonised by seagrasses (Carrigy, 1956; Hollings, 2004). The inshore region of Warnbro Sound is almost completely protected from offshore wave energy by offshore limestone reef systems that are parallel to the shore (Five Fathom Bank & Garden Island Ridge) (Carrigy, 1956).

Commercial catch and effort

All commercial fishers operating in Western Australian waters submit statutory monthly returns that report total catch of all retained species and an estimate of fishing effort. Annual commercial catch and effort for the Swan-Canning Estuary and Warnbro Sound is presented by calendar year. Catch is reported by weight (tonnes). Effort for the Swan-Canning Estuary is presented in numbers of fisher days in which nets are set and pulled, while effort for the trap fishery in Warnbro Sound is presented in numbers of traplifts.

Commercial monitoring

Monitoring of commercial blue swimmer crab catch and effort commenced in the Swan-Canning Estuary in November 2007 and in Warnbro Sound in March 2007. Once a month, commercial fishers were accompanied by research staff during daily crabbing operations (in each month that fishing occurred), and the day's catch and effort recorded. Fishers in the Swan-Canning Estuary serviced up to 480 m of net (usually in lengths of 120 m) per day, while Warnbro Sound fishers serviced up to 100 hourglass traps per day. Monitoring was undertaken on a randomised day during each month. Carapace width (the distance between the tips of the two lateral spines of the carapace measured to the nearest millimetre), sex, moult stage, female breeding condition, the number of traps in the line, soak time (number of hours the traps have been in the water since they were last serviced) and a latitude, longitude and depth were recorded.

4.2.2 Results

Swan River

'Commercial' fishing in the Swan-Canning Estuary commenced shortly after European settlement in 1829 (Smith, 2006). While as many as 130 fishers have operated annually in the fishery, a 'Voluntary Fishery Adjustment Scheme' (VFAS) has reduced the numbers of registered vessels from approximately 30 vessels throughout the 1960s and 1970s, to just a single fisher in 2009.

Historical annual commercial crab catches in the Swan-Canning Estuary have fluctuated dramatically, ranging from 6 t to 29 t between 1990 and 2009 (mean 16 t). After peaking at almost 30 t in 1998, the annual crab catch has steadily declined in line with the removal of fishing effort (VFAS), to around 10 t in 2009 (Fig. 4.1).

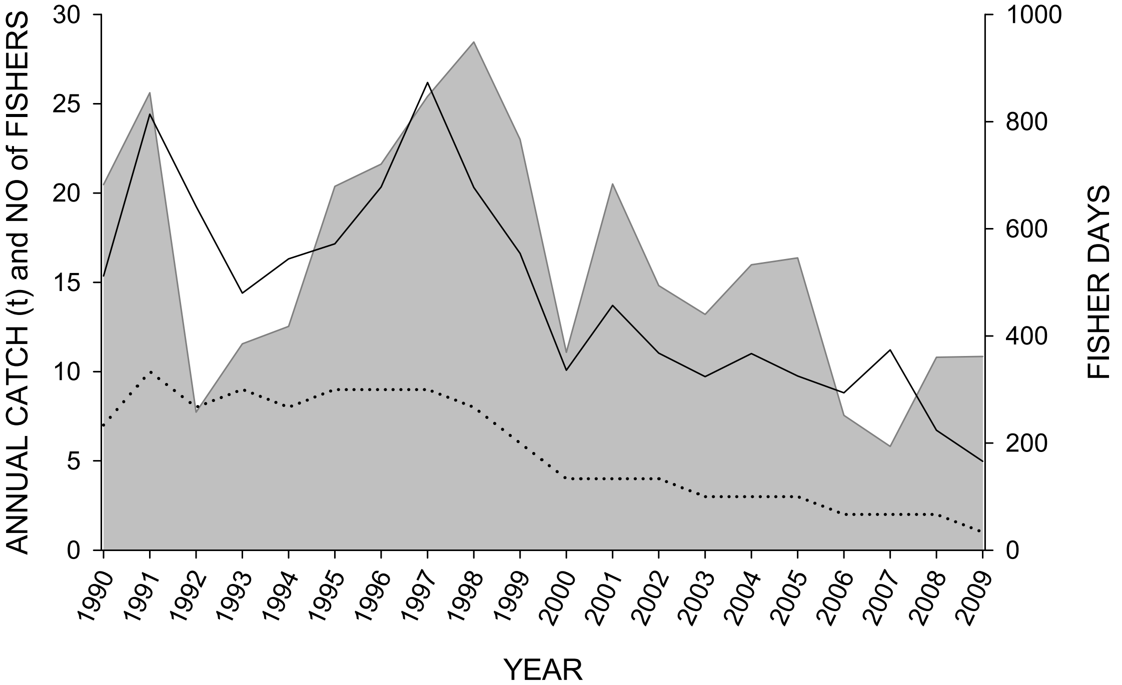


Figure 4.1. Annual commercial blue swimmer crab catch (t) and effort (numbers of fishers and total numbers of fisher days) from Area I of the West Coast Estuarine Managed Fishery (Swan-Canning Estuary) from 1990 to 2009. Catch and effort are presented by calendar year. Total catch (■); Number of fishers (·······); total fisher days (—).

Most of the annual commercial crab catch in the Swan-Canning Estuary was taken during the summer months, with commercial quantities of blue swimmer crabs first appearing in nets in December as the water temperature increases. Forty percent of the catch was landed by the end of January, and over 90% by the end of April. The cooler, wetter months from May to November contributed less than 10% of the catch (Fig. 4.2).

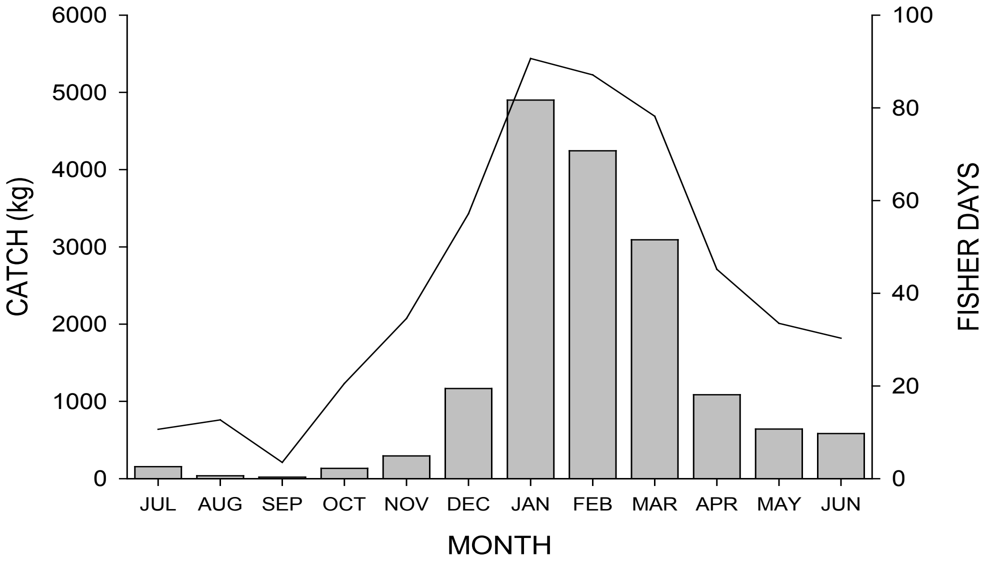


Figure 4.2. Mean monthly commercial blue swimmer crab catch (t) and effort (fisher days) from Area I of the West Coast Estuarine Managed Fishery (Swan-Canning Estuary) between 1990 and 2009. Catch (■); fisher days (—).

The crab catch sampled during commercial catch monitoring surveys over summer was predominantly male with only a small proportion of berried and non-berried female crabs captured in the nets (Fig. 4.3). The catch remained almost exclusively male (>95%) through to the end of April, when non-berried females began to appear. By the end of May, the commercial catch was composed mainly of non-berried female crabs (65%), and remained so through the rest of the season (Fig. 4.3).

Berried female crabs were noticeably absent from the commercial catch in the Swan-Canning Estuary, only appearing in small numbers in December (<3% of the total catch) and January (<2%) (Fig. 4.3).

The commercial blue swimmer crab catch from the Swan River comprised a single age cohort (2+) with virtually no undersize crabs appearing in the nets (Fig. 4.3). The mean size of males and females sampled during catch monitoring surveys in December was 154 mm CW and 147 mm CW, respectively (Fig. 4.3). As the season progressed, mean size increased slightly through to April (160 mm CW for males; 155 mm CW for females) as animals continue to moult (Fig. 4.3).

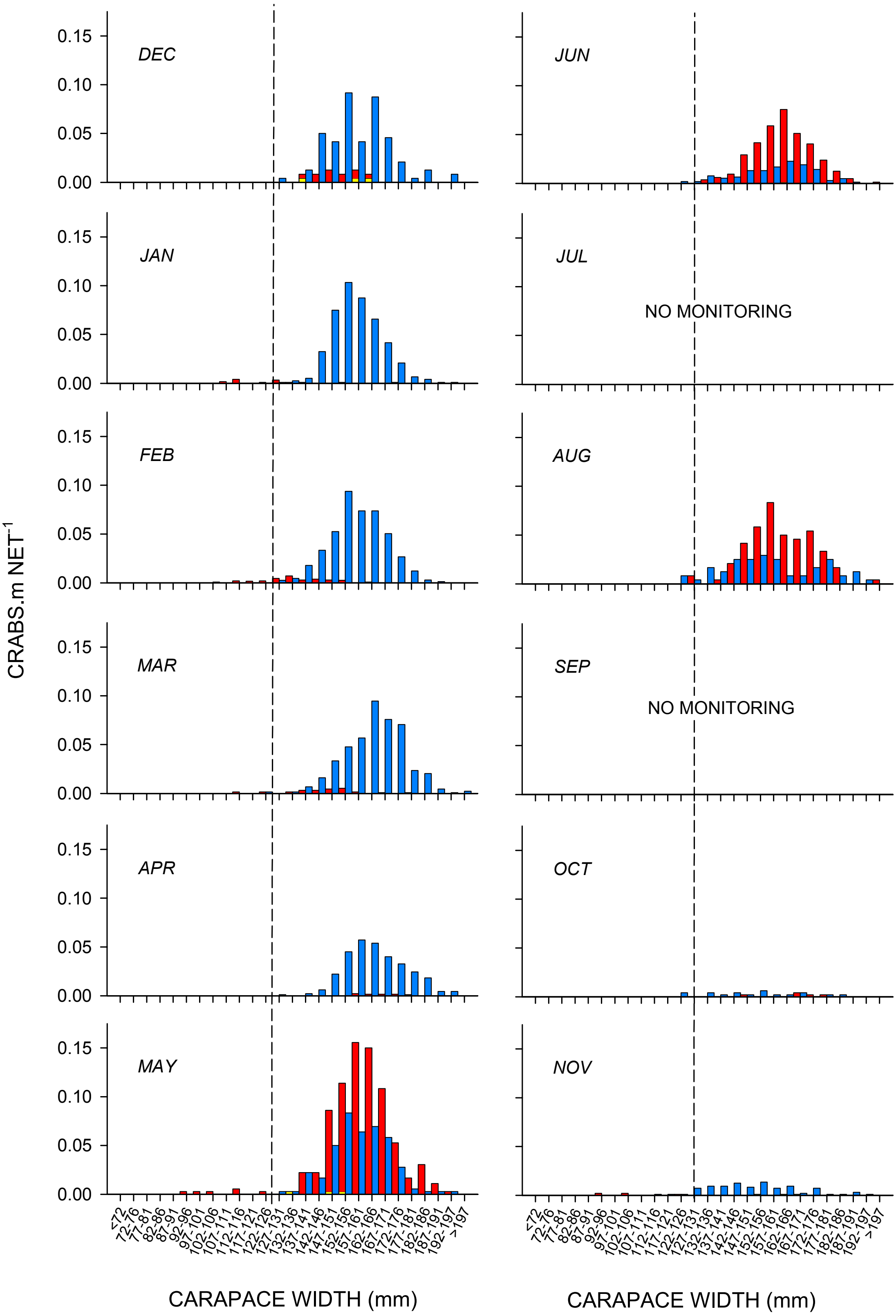


Figure 4.3. Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard commercial vessels in Area I of the West Coast Estuarine Managed Fishery (Swan-Canning Estuary) between November 2007 and April 2010 inclusive. Minimum commercial size limit (- - -).

Warnbro Sound

A single operator has been endorsed to fish commercially for blue swimmer crabs in Warnbro Sound since 1985. The fisher originally employed gill nets, but began trialling hourglass traps in unison with Cockburn Sound fishers during 1994. He has fished exclusively with traps since the gazetting of the Warnbro Sound Crab Limited Entry Fishery in 1995.

As with the Swan-Canning Estuary, annual commercial blue swimmer crab catches in Warnbro Sound have fluctuated dramatically between 1990 and 2009 ranging from <1 t to 17 t, with fishing effort tending to follow catch trends (Fig. 4.4). Catch and effort was low during the period when gill nets were used (annual catch < 4 t), partly because fishing was restricted to the summer months due to the catchability of the nets (Fig. 4.5). With the move to hourglass traps in 1995, however, fishing could be conducted all year round and an increase in annual catch and effort has resulted (Fig. 4.4 and 4.5).

While more crabs were captured in Warnbro Sound over the summer months than in the winter, catch and effort was much more consistent between months than most blue swimmer crab fisheries on the lower west coast of Western Australia (Fig. 4.6). When the season opened in December, the catch was evenly split between male and female crabs, with a third of the female crabs ovigerous. Large quantities of berried females continued to appear in commercial traps through January although numbers dwindled in February and male crabs formed the bulk of the catch. This male dominance lasted only a month, however, with non-berried females forming the bulk of the catch from March through to the end of the fishing season in September (Fig. 4.7).

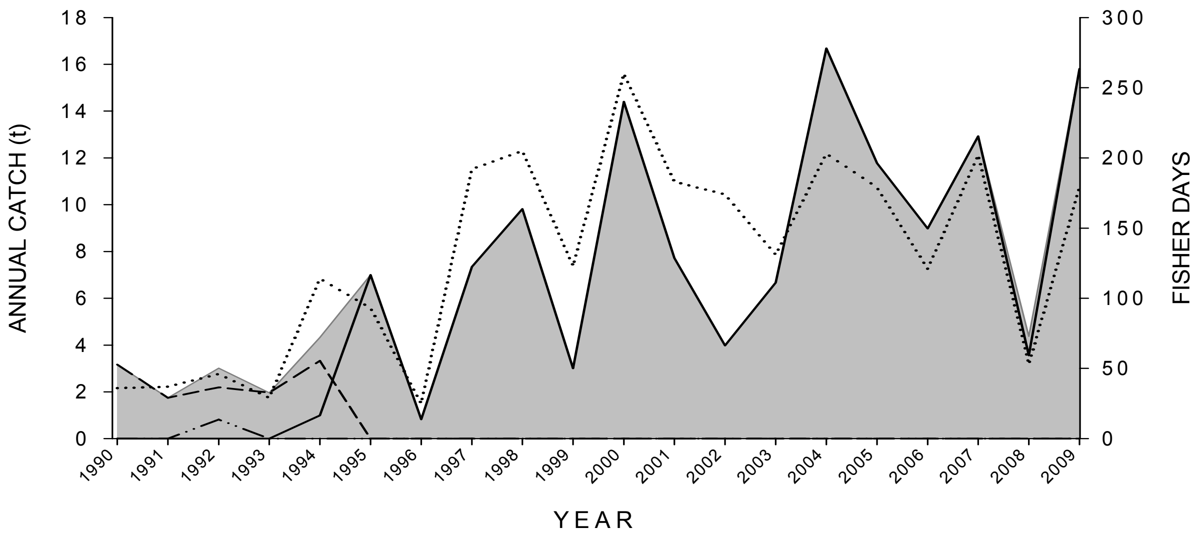


Figure 4.4. Annual commercial blue swimmer crab catch (t) from Warnbro Sound by fishing method and overall effort (fisher days) irrespective of method. Annual catch is presented by calendar year. Total catch (■); gill nets (----); crab traps (—); other (–··–) and effort (·······).

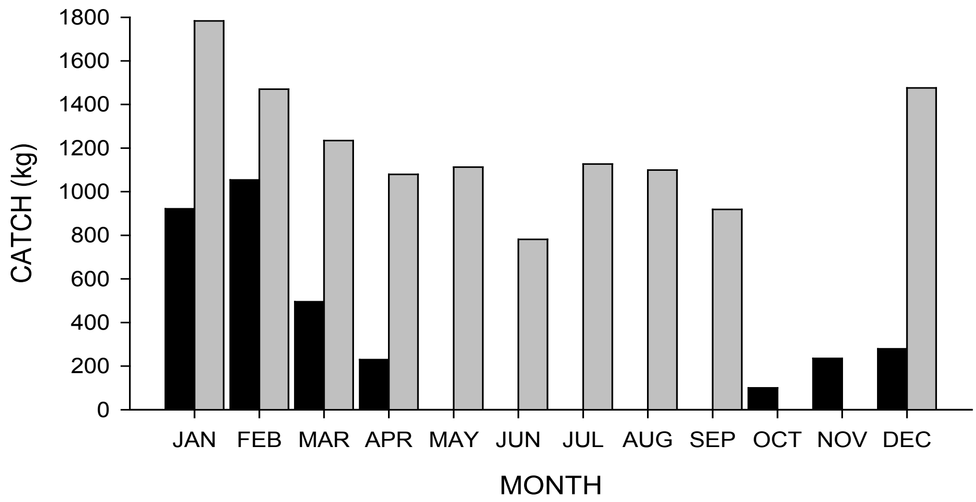


Figure 4.5. Mean monthly commercial blue swimmer crab catch (t) from Warnbro Sound using gill nets (■ ; 1985 – 1993) and hourglass traps (■ ; 1995 – 2009).

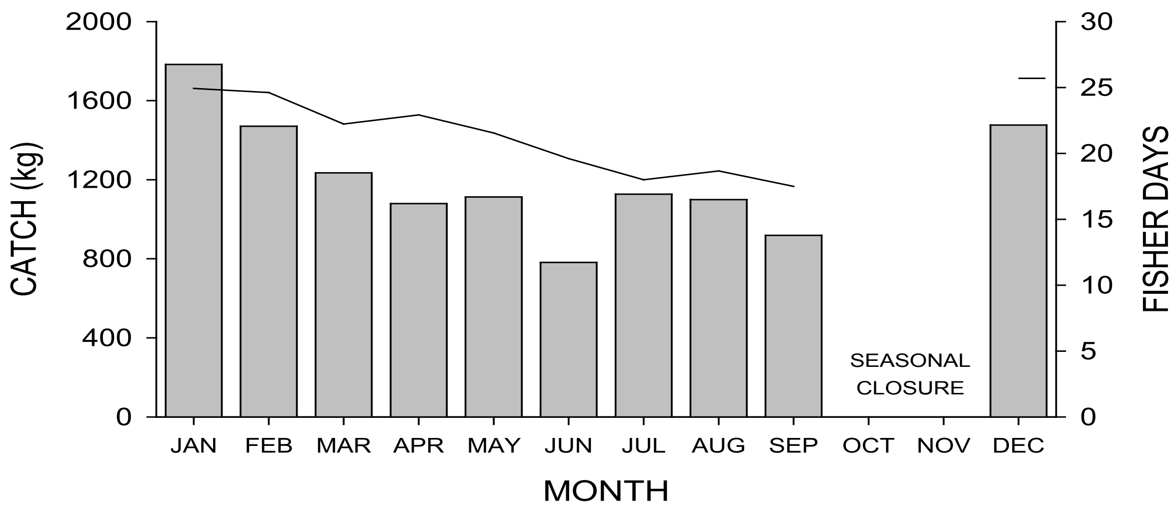


Figure 4.6. Mean monthly commercial blue swimmer crab catch (t) and effort (fisher days) from Warnbro Sound between 1995 and 2009. Total catch (■); total fisher days (**—**).

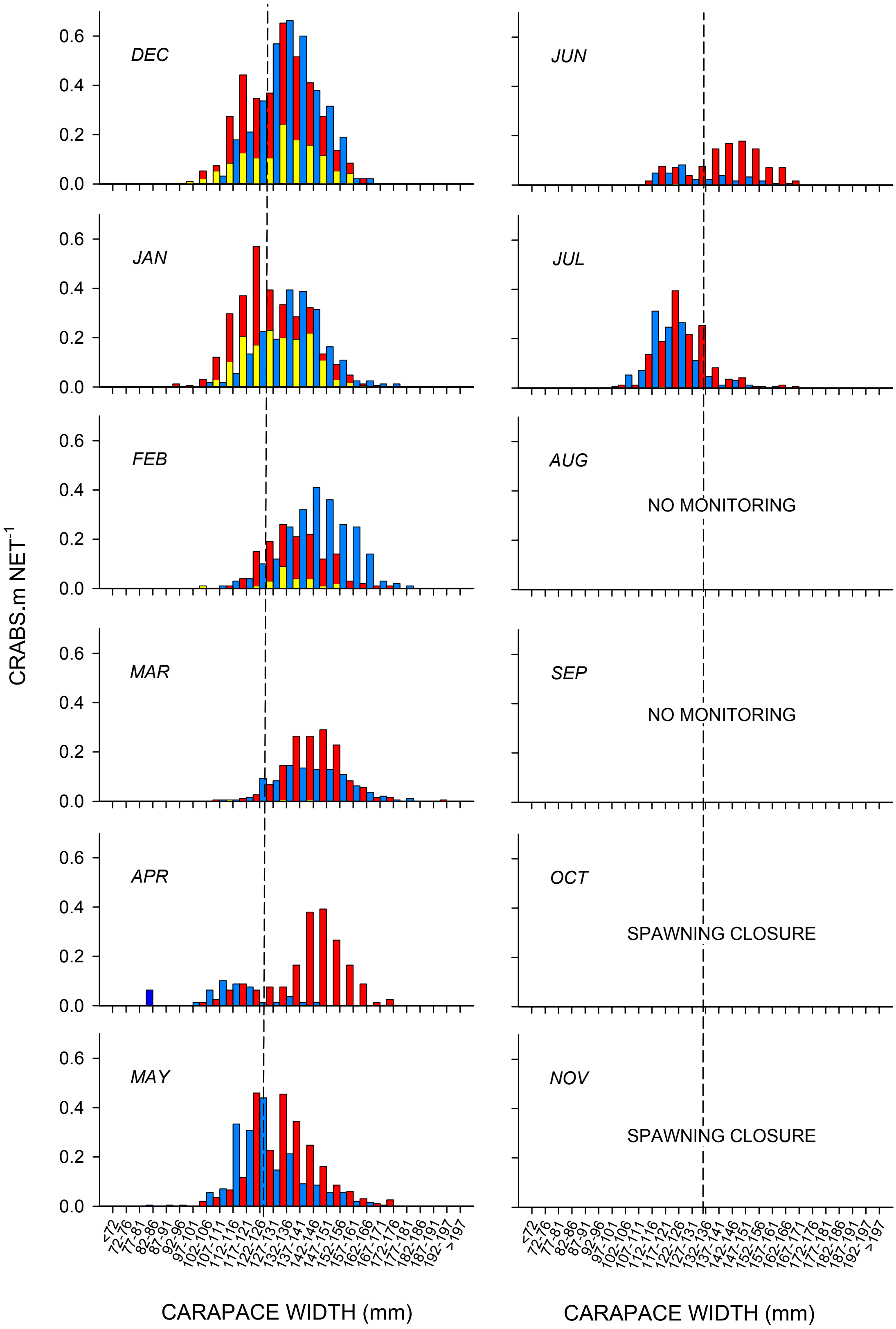


Figure 4.7. Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard commercial vessels in Warnbro Sound between March 2007 and April 2010 inclusive. Minimum commercial size limit (- - -).

4.2.3 Discussion

While the commercial blue swimmer crab fisheries in the Swan River and Warnbro Sound are smaller in volume and monetary value than neighbouring Cockburn Sound, they provide highly valued recreational crabbing opportunities given their proximity to the Perth metropolitan area. The Swan River fishery, in particular, also plays a significant role in supplying the local market with a premium product (due to its larger size) that attracts significantly high prices than blue swimmer crabs from all other locations.

With no fishery-independent sampling in the Swan River and Warnbro Sound over the past three years, information on the stock was restricted to commercial catch monitoring surveys. This data suggests blue swimmer crabs in the Swan-Canning Estuary follow the typical catch history of an estuarine stock on the lower west coast of Western Australia. Substantial quantities of adult crabs first appear in commercial nets and recreational pots in December, with the majority of the commercial and recreational catch taken between December and May. As in the Peel-Harvey Estuary, the catch during this period is almost exclusively male. At some point around April-May, the catch switches from male to female, with the proportion of female crabs in the catch increasing until winter rains enter the river catchment and lowers salinity and flushes stocks downstream from the fishery. Consequently, both commercial and recreational fishing normally ceases in winter and spring, recommencing the following December.

The Swan River crab stock also exhibits the estuarine characteristic of an absence of ovigerous females in the commercial catch. While significant quantities of berried females are encountered in open marine embayments on the lower west coast of Western Australia annually between September and February, virtually no ovigerous females are captured in commercial gear in either the Swan-Canning Estuary or the Peel-Harvey Estuary at any time of the year. This presumably results from the flushing of the mated pre-spawning female stock either further downstream from the boundaries of the commercial fishery or from the river system entirely.

The most notable aspect of crabs from the Swan River, and the reason they attract a premium price at market, is their large size and distinct dark colouring. The mean carapace widths of male and female crabs sampled during commercial catch monitoring surveys in December were 154 mm CW and 147 mm CW, respectively, with the mean size increasing through to April (male: 160 mm CW; female: 155 mm CW) as animals continue to moult. By comparison, males and females in the commercial catch from Cockburn Sound were significantly smaller, with mean carapace widths in December of 131 mm CW and 134 mm CW, respectively, increasing slightly through to March (male: 136 mm CW for males; female: 138 mm CW) before decreasing by July (males: 129 mm CW; females: 133 mm CW) as fishing pressure removed the larger crabs in the stock. Large crabs similar in size to those caught commercially have also been reported during recreational surveys in the Swan River (Malseed and Sumner, 2001), so that this important biological characteristic is demonstrated in both the commercial and recreational sectors of this fishery.

Further evidence of this size anomaly could be seen in the proportion of undersize crabs in the commercial catch. Virtually all crabs captured during commercial catch monitoring surveys in the Swan River were above the legal size limit, whereas the mean monthly proportion of undersize crabs in Cockburn Sound ranged from 28% to 47%.

The reasons for the large size of Swan River crabs may be due to the Cockburn Sound and the Swan River being a single stock, with the larger crabs in the Swan River comprising the 2+ age cohort. The difference in carapace width of commercially caught blue swimmer crabs from the Swan River over crabs from Cockburn Sound was 23 mm for males and 17 mm for females. As with all crustaceans, blue swimmer crabs increase in size step-wise as they moult and this measurement correlates with the average increase in carapace width between the post-pubertal and terminal moult for blue swimmer crabs on the lower west coast of Western Australia, which occurs during the third summer of the crab's lifecycle. Given the commercially captured stock in both fisheries represent single age cohorts, and that genetic studies have confirmed a level of inter-relatedness between the two stocks (Chaplin and Sezmis, 2008), it is possible that the larger crabs found in the Swan River are the 2+ cohort from Cockburn Sound migrating upstream.

Alternatively, the bathymetry and ecology of the Swan-Canning Estuary might help explain the larger crabs found in this fishery. Deep channels and corrugations caused by strong tidal flow could provide areas of refuge from fishing pressure that allow crabs to survive through to their third year. Conditions such as higher quality prey species may also promote superior growth rates compared with other south-west fisheries.

Unfortunately, it is not possible for catch monitoring data from the commercial fishery to confirm either of these hypotheses. The data is limited spatially, as commercial fishing is restricted to the waters upstream from Point Walter to Heirisson Island on the Swan River and Salter Point on the Canning River. Furthermore, commercial fishers target adult male crabs and avoid nursery and spawning areas.

The Warnbro Sound blue swimmer crab stock appears to follow the typical catch history of an open marine embayment stock on the lower west coast of Western Australia. As with Cockburn Sound and Comet Bay, the catch in December is divided relatively evenly between male and female crabs, with a significant proportion of the females ovigerous in the summer. There are also significant numbers of undersize crabs in the catch.

As with the Swan River, commercial catch monitoring data from Warnbro Sound on its own is not necessarily a reliable indicator of stock parameters. Due to intermittent fishing practices, the sampling regime was sporadic. Over the three year period covered by the study, monthly catch monitoring surveys were conducted in two years for the months of January, March, May, June and July, one year for February, April and December and not at all in August and September. Monitoring data was also not available for October and November, as these months span the peak spawning period and the commercial fishery is closed. Consequently, the data collected may not be a true representation of normal stock dynamics in Warnbro Sound. However, the similarity with Cockburn Sound, where a 12-year data set provides confidence in the commercial catch data's representation of that fishery's stock dynamics, suggests general trends in the Warnbro Sound data are legitimate.

As with most commercial catch information, the data from Warnbro Sound is spatially limited. Fishing during monitoring trips was restricted to the shallow (< 4m) banks to the south and north of Warnbro Sound, with virtually no activity in the broad, deeper central basin. Furthermore, commercial fishers target adult male crabs and prefer to avoid nursery and spawning areas.

4.3 Recreational crabbing

The third objective of this aspect of the study was to:

Investigate whether data is available on recreational crab catch rates for Swan River and Warnbro Sound by examining existing creel surveys, Research Angler and VFLO programs.

Several creel surveys quantifying recreational fishing catch and effort in the metropolitan area have been conducted by the Department of Fisheries (DoF) over the past 15 years. A 12-month survey was conducted specifically in the Swan-Canning Estuary during 1998/99, with recreational blue swimmer crab catch and effort data reported (Malseed and Sumner, 2001). The remaining surveys, however, include metropolitan coverage as part of wider recreational fishing surveys covering the West Coast bioregion of Western Australia. While reports on these surveys have quantified data on finfish species only, data on blue swimmer crabs was also collected and could provide estimates of recreational crab catch and effort for the Swan River and Warnbro Sound for the 2005/06, 2007/08, 2008/09 and 2009/10 survey years. A summary of these surveys is provided below. A review of Fisheries Research Report 177 was undertaken by Steffe (2009) to assess the recreation fishing survey methods used. Any further analysis of the datasets presented in Fisheries Research Reports 126 and 177 should take the recommendations of this review into account.

Additional information on recreational fishing in the metropolitan area has been collected through two DoF community initiatives: a volunteer fisheries liaison officer (VFLO) program that operated from 1995 to 2007; and the current Recreational Angler's Daily Log Book Program, which was launched in March 2004 as part of the DoF Research Angler Program (RAP). While published reports on these programs have quantified data on finfish species only, data on blue swimmer crabs was also collected and could provide estimates of recreational crab catch and effort for the Swan River and Warnbro Sound. As per any logbook it is not always possible to distinguish whether any trends in the catch rates identified by either program relate to changes in abundance or simply show changes over time in fishing efficiencies.

4.3.1 Recreational fishing survey in Swan-Canning Estuary Basin 1998-99

A survey of recreational boat-based and shore-based fishing in the Swan-Canning Estuary Basin was conducted between August 1998 and July 1999 by Sumner and Malseed (2001).

During the survey 1,302 interviews were conducted at boat ramps. The majority of these (62%) were not involved in fishing or crabbing activities, with a further 18 per cent fishing in the adjacent ocean. Of the remainder, 139 boats had been crabbing and 154 angling (29 were both crabbing and angling) within the Swan-Canning Estuary Basin. In addition to the interviews at boat ramps, 378 shore-based fishing parties were interviewed.

The survey estimated the total annual boat-based recreational fishing effort as 22,265 fisher days, with 44 per cent of this effort targeting blue swimmer crabs. The total annual shore-based recreational fishing effort was estimated to be 8,073 fisher days, with only 9 per cent of this effort targeting blue swimmer crabs. The estimated total recreational catch of blue swimmer crabs from the Swan-Canning Estuary Basin between August 1998 and July 1999 inclusive was 20,875 crabs or 7.3 tonnes. This consisted of a boat-based catch of 20,176 crabs and a shore-based catch of 699 crabs. Most crabs (94%) kept by recreational fishers were male.

Less than one per cent of boats with two or more people on board achieved the daily boat limit of 48 crabs. However, a larger proportion (7.1%) of boats with only one person on board achieved their daily bag limit of 24 crabs. No anglers caught their daily bag limit of any fish species.

4.3.2 Recreational boat-based fishing survey Augusta and Kalbarri 2005-06.

A 12-month survey of boat-based recreational fishing in the West Coast Bioregion (Augusta to Kalbarri) of Western Australia was conducted at boat ramps between 1st July 2005 and 30th June 2006 by Sumner et al. (2008).

While catch and effort data was recorded for all recreational species captured during the survey, this report covered finfish species caught by line only. The West Coast Bioregion surveys were repeated for the 2008/09 and 2009/10 financial years, with the metropolitan area surveyed in 2007/08. Analysis of these datasets may provide recreational blue swimmer crab catch rates for both the Swan River and Warnbro Sound.

4.3.3 Angler's Daily Log Book and Fishing Tournament Monitoring 2004-2006

The Department of Fisheries (DoF) Recreational Angler's Daily Log Book Program was launched in March 2004 as part of the Research Angler Program (RAP) (Smith et al., 2007). The current logbook format was based on an earlier version with all anglers participating in the logbook program supplied with new versions during 2004/05. The current logbook is available in 2 formats – "Ocean Edition" and "Estuary Edition". The Ocean Edition is designed for all types of ocean beach and offshore fishing, while the Estuary Edition is designed for all types of estuary and freshwater fishing. Both editions accommodate data on finfish and invertebrate catches. The logbook program is voluntary.

Smith et al. (2007) summarises data reported by logbook anglers in 2004 and 2005 for finfish species only. However, the logbook also collects data on recreational crab catch and effort. The logbook program is continuing, so analysis of the logbook dataset could provide recreational blue swimmer crab catch rates for both the Swan River and Warnbro Sound from 2004 onwards.

4.3.4 Volunteer Fisheries Liaison Officer program: recreational fishing data 1995–2007

The analysis of recreational fishing data provided by the Volunteer Fisheries Liaison Officer (VFLO) program between 1995 and 2007 was summarised by Smallwood et al. (2010). VFLOs are a group of individuals who participate in volunteer activities promoting sustainable fishing amongst recreational anglers. The program is a Department of Fisheries initiative that has been running since 1993 and, during this time, >600 volunteers have participated in a variety of activities. The aim of their report was to explore the data collected by VFLOs from 1995-2007 in each of the state's four marine bioregions. During this period, volunteers undertook >2,000 days of activities, the majority of which were educational displays at events such as boat shows and patrols in coastal, marine and estuarine environs. Patrols focused on interviews with recreational anglers to provide information about sustainable fishing and collect data on catch and effort. These activities were concentrated within the West Coast bioregion, particularly the Perth metropolitan area and Mandurah along with regional centres such as Carnarvon and Albany. The peak period for volunteer activities corresponded to the 'high' or tourist season in each bioregion. A re-branding of the VFLO program in 2008 facilitated a shift towards educational activities and away from patrols and their associated interviews with groups participating in recreational fishing from boats and the shore. However, the efforts of these volunteers produced a longitudinal dataset of recreational fishing activity throughout Western Australia, with 226 species and categories of aquatic organisms retained or released by recreational fishers. The most frequently retained species were blue swimmer crabs, Australian herring, general/sand whiting and tailor. Although there were data limitations due to unstructured sampling strategies as also occurs in logbook programs, catch rates were calculated for the main species retained by recreational fishers in each bioregion.

Recreational fishers interviewed by VFLOs during patrols in the West Coast bioregion were predominantly shore (70%) and boat-based (24%), which encompasses all groups targeting finfish, crabs or western rock lobster. Diving as method of fishing was undertaken by 1% of groups while the remaining 6% of respondents had no information recorded on their type of fishing platform.

There were 162 species and general categories of aquatic organisms retained or released by recreational fishers in the West Coast bioregion. The most frequently recorded by shore fishers were Australian herring, blue swimmer crabs, tailor (*Pomatomus saltatrix*), general/sand whiting, silver bream (*Rhabdosargus sarba*) and yellow-fin whiting. For boat-based fishers, the most frequently caught were blue swimmer crabs, Australian herring, general/sand whiting, western rock lobster (*Panulirus cygnus*), yellow-fin whiting, unknown species, skipjack trevally and King George whiting (*Sillaginodes punctata*).

While interviewers recorded catch and effort data for all recreational species captured, Smallwood et al. (2010) presents catch rates for finfish species only. Furthermore, the data is presented either for the whole state or by region (other than a specific survey in the Peel-Harvey Estuary in 2007/08) and provides no information on recreational catch and effort specific to the Swan River or Warnbro Sound. The data could provide specific catch rates for the two fisheries, however, would need to be based on where the interview was recorded by assuming that all fishers interviewed at Warnbro Sound and Swan-Canning Estuary crabbed exclusively in these locations. Once again, similar to logbook data it may be difficult to distinguish whether trends in catch rates relate to changes in abundance or changes over time in fishing efficiencies.

5.0 Stock Status of the Cockburn Sound Crab Fishery

5.1 Introduction

The chapter provides an assessment of the current status of the crab resource using available data. It forms the basis of research advice provided to managers and industry for use in the management of this fishery.

Information on the management of the Cockburn Sound blue swimmer crab fishery, the biology of blue swimmer crabs in Western Australia and Cockburn Sound and the commercial and recreational crab fishery in Cockburn Sound is in Chapter 1. Detailed analysis of the factors contributing to the collapse of the fishery in 2006 is described in Johnston et al. (2011) (Chapter 2) and a stock recruitment-environment relationship has also been developed by de Lestang et al. (2010) (Chapter 3). Key figures from these papers have been updated and used in this chapter. Summarized versions of methods for fishery-dependent and fishery-independent programs conducted on the fishery are provided in Chapters 2 and 3 (and are relevant to the assessment presented in this chapter).

5.2 Fishery Overview

Due to the relatively slow recovery of juvenile recruitment and spawning stock levels in the Cockburn Sound Blue Swimmer Crab fishery (Johnston et al. 2011, Chapter 3), the fishery remained closed to commercial and recreational fishing for 3 years (December 2006- December 2009). However, assessment of data during 2009 suggested that the recovery was sufficient to allow a precautionary approach to re-opening the fishery for the 2009/10 season. Research advice was provided around the potential impacts of: (1) an increase in the minimum commercial size limit from 130 mm CW to 135 or 140 mm CW; (2) reduction in commercial trap numbers; and (3) prohibited winter fishing and reduced season length. Based on this advice the fishery was re-opened under the following management conditions: reduced season length from 10 months to 3.5 months (December 15, 2009 to March 31, 2010), 20% trap reduction, and an increase in commercial size limit from 130 mm CW to 140 mm CW, with the recreational fishery size limit remaining at 127 mm CW. This report will provide an update of the stock status of crabs in Cockburn Sound focusing on the 2009/10 season and 2010 research program and will provide advice on the 2010/11 season.

5.3 Methods

Methods for the Cockburn Sound crab fishery research program are detailed in Chapter 2. This section will focus on updates for the commercial fishing season and research program conducted during 2010.

5.3.1 Commercial monitoring

Following the closure of the fishery in December 2006, a commercial crab fisher was contracted to replicate commercial fishing in Cockburn Sound. Accompanied by research staff, the fisher set 100 traps in lines of 10, twice a month throughout the traditional fishing grounds. Standard commercial hourglass traps were used, with nine of the ten traps in each line made of 3½ inch mesh on the top half of the trap and 2 inch mesh on the bottom half, and the remaining trap made entirely of 2-inch mesh. The soak time for all traps set was 24 hours. This arrangement was kept in place during the closure from December 2006 to November 2009. From 15 December 2009, normal commercial monitoring was resumed with all fishers sampled during the 2010 fishing season. From April 1, 2010 the fishery was closed and the same commercial fisher was contracted to replicate commercial fishing through to December 2010. The months sampled during the commercial monitoring program since 1998 is summarised in Table 5.1.

5.3.2 Fishery-independent sampling – breeding stock

Following the closure of the fishery in December 2006, the spatial coverage of the *RV Naturaliste* trawl surveys in Cockburn Sound was extended. Since April 2007, trawling has been conducted at six sites in addition to the Research Area (Fig. 5.1), on two consecutive nights in April and again in December. A 12-month project to assess the biodiversity of the flora and fauna in Cockburn Sound was also incorporated into the program (Johnston et al., 2008). As the project required the catalogue of all biota captured in each trawl, 20-minute shots were found to generate more biota than could be processed while still covering all seven sites in the available time. Trials in the Research Area determined that 5-minute trawls could provide as representative a crab sample as 20-minute trawls, so all shots were shortened to 5 minutes. Three 5-minute trawls were conducted at each of the seven sites. Months sampled for the fishery independent survey (breeding stock) since 2001 is summarised in Table 5.1.

5.3.3 Fishery-independent sampling – juveniles

The juvenile trawl program continued during 2010 as per description in Chapter 2. The months sampled from 1998 is presented in Table 5.1.

5.3.4 Catch prediction model

The catch prediction model was updated for 2010 as described in Chapter 2.

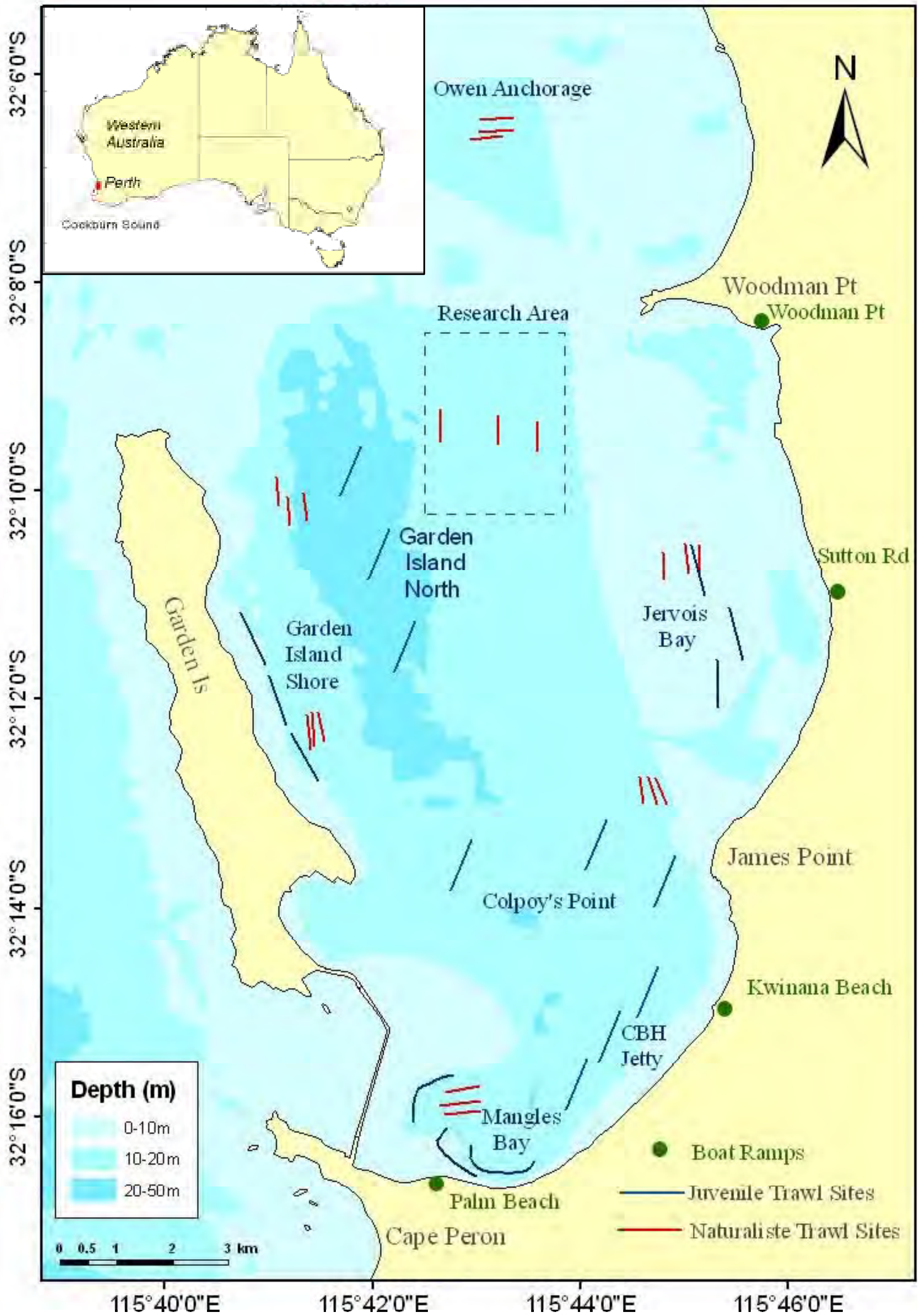
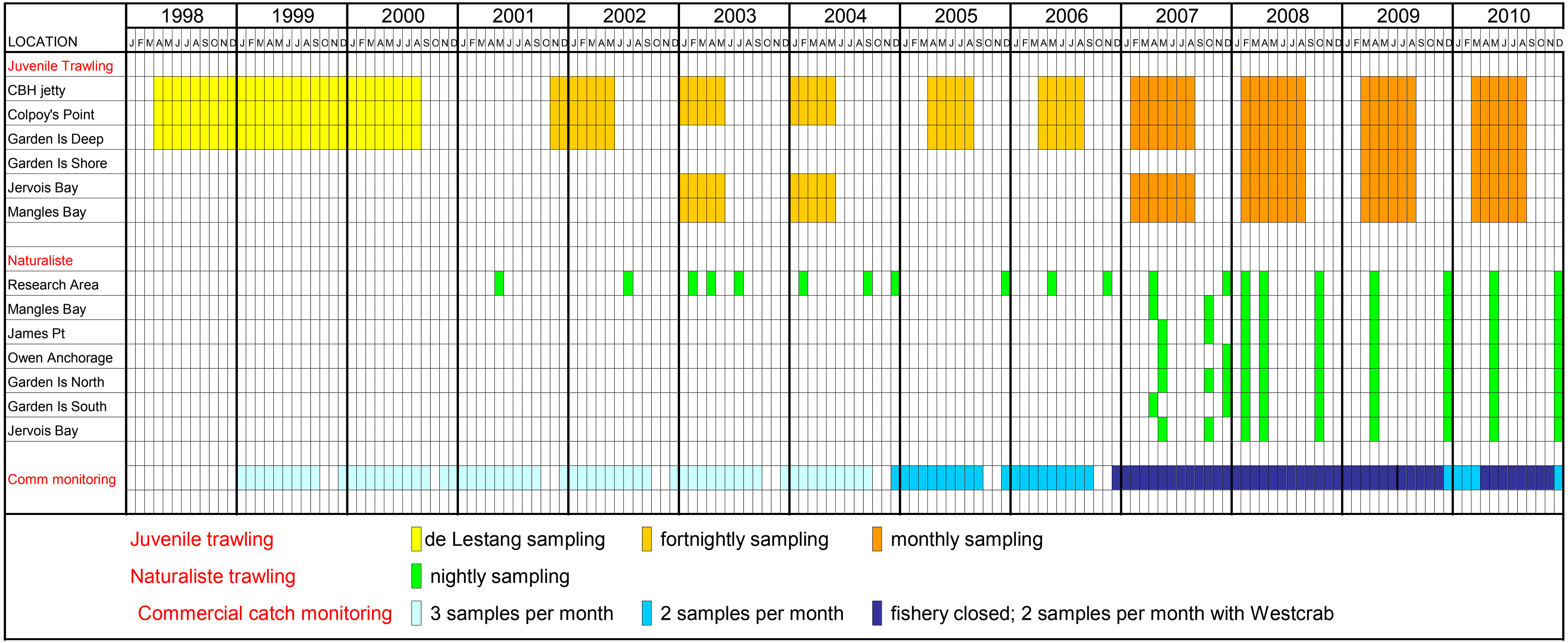


Figure 5.1. Map highlighting the location of Cockburn Sound within Western Australia and the sites sampled during creel (●), juvenile (—) and Naturaliste (—) trawl surveys conducted by the Department of Fisheries between 2002 and 2008.

Table 5.1. Department of Fisheries research sampling and Murdoch University juvenile trawling intensity in Cockburn Sound since 1998.



5.4 Results

5.4.1 Catch and Effort

Reopening the fishery under the limited management regime described above (20% trap reduction, 3.5 month season and 140 mm CW size limit) resulted in a total commercial catch of 56 t for the 2009/10 season (Fig. 5.2). This was the level of catch expected under these management conditions. The CPUE for the 3.5-month period averaged 0.91 kg/trap lift, with a steady decline in catch rate occurring from December (1.15 kg/traplift) to March (0.8 kg/traplift) (Fig. 5.3). This refected the decline in numbers as crabs above 140mm CW were caught. The full complement of traps was utilised (800 less 20% - 640 traps), with very little latent effort in the fishery during the 2009/10 season. This is in contrast to an average 20% latent effort (80% pots utilised) during previous commercial seasons prior to closure. Although commercial catch was low compared with productive years prior to closure, the market value of crabs was significantly higher due to their large size (>140 mm CW).

The recreational sector of the fishery has been managed through bag limits, with catches prior to closure between 18 and 23 t, representing between 5% and 15% of total catch (see Chapter 1) (Sumner and Williamson, 1999; Sumner and Malseed, 2004; Bellchambers et al., 2005). Like commercial catch, recreational catch estimates in 2005/06 had also declined significantly to approximately 3 t (Sumner, unpubl. data). A recreational survey was conducted to estimate crab catch following opening of the fishery during the 2009/10 season. Methods for this survey are outlined in Appendix 1. Data is currently being analysed.

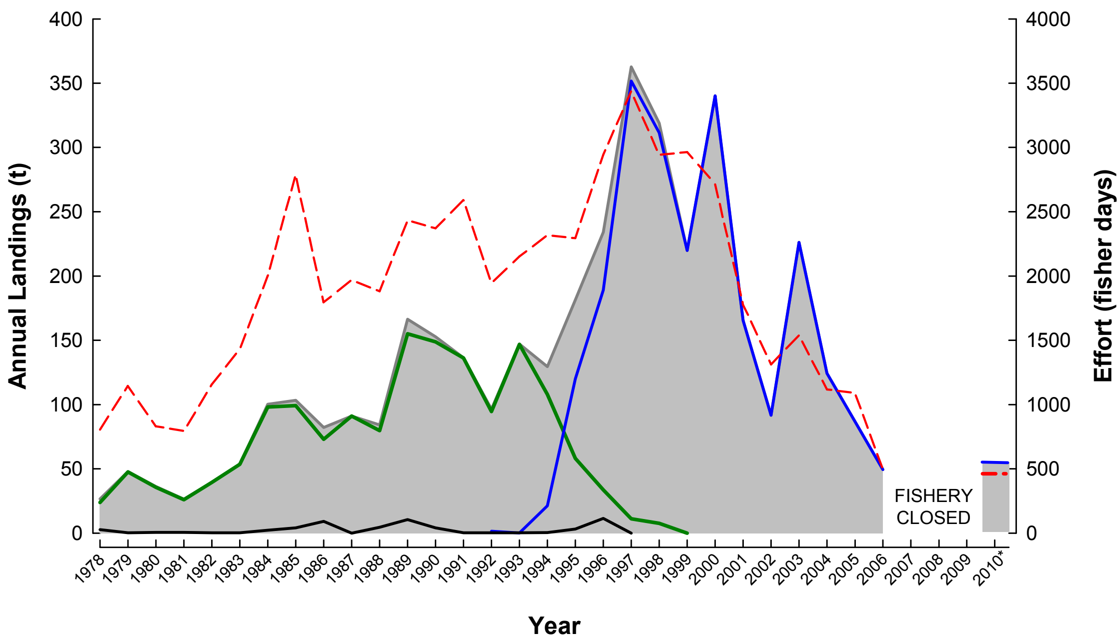


Figure 5.2. Annual commercial blue swimmer crab catch (t) from the Cockburn Sound Crab Managed Fishery by fishing method and overall effort (fisher days) irrespective of method. Annual catch is presented as commercial fishing season ie. 2006 covers the period from December 2005 to November 2006.Total catch (■); gill nets (—); crab traps (—); other (—) and effort (----). * 2010 fishing season was limited to Dec 15 2009 – Mar 31 2010 inclusive, and incorporated a 20% trap reduction, and an increase in the minimum legal size limit from 130mm CW to 140mm CW.

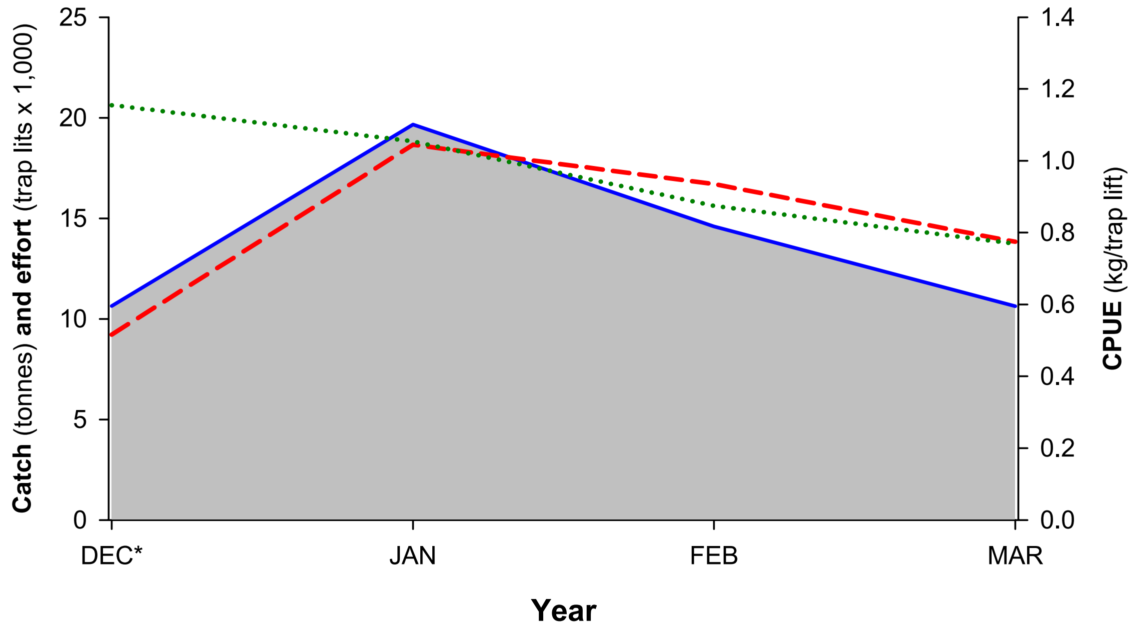


Figure 5.3. Commercial blue swimmer crab trap catch (t), effort (trap lifts x 1,000) and catch per unit effort (kg/trap lift) by month for the 2010 season of the Cockburn Sound Crab Fishery. Total catch (—); effort (----), and catch rate (······). * Only half the month was fished in December as the 2010 fishing season was restricted to Dec 15 2009–Mar 31 2010 inclusive, with a 20% trap reduction, and an increase in the minimum legal size limit to 140 mm CW.

5.4.2 Commercial monitoring

Prior to closure, monthly catch monitoring aboard commercial vessels showed that at the beginning of the season in December, the catch was composed predominantly of female blue swimmer crabs (see Fig. 2.4 Chapter 2). Within two weeks the catch was divided evenly between males and females, and by January was almost exclusively male. Up to 90% of the female crabs captured during December were ovigerous. Males then dominated the commercial catch through the summer months. In March or April, the catch switched from predominantly male to mainly non-ovigerous females and the high proportion of females continued through the rest of the season (Fig. 2.4). Ovigerous females first appeared in September or October, with spawning triggered by the rise in spring water temperatures. Regardless of fluctuations in crab abundance, this pattern of variation in sex ratio of the commercial catch was consistent between years.

During closure of the fishery (December 2006 – December 2009), the ratio of male and female crabs caught in traps at different times of the year has changed. Catches during the summer months (January-March) were still dominated by males (72-81%) (Fig. 5.4). But while female crabs enter traps in March/April, males continued to make up the majority of the catch until June and were caught in significant quantities through to December when they become dominant in catches again. Prior to closure, 33% of crabs caught by the commercial fishery in April were male whereas after the closure, the mean proportion of males from April to June rose to between 57% and 68% (Fig. 5.4). This trend was most likely attributed to males not being fished and depleted in summer. Sampling was also conducted for the first time during the seasonal closure (October and November), with data clearly showing that the abundance of ovigerous females is highest in these months justifying the previous spawning closure (Fig. 5.4).

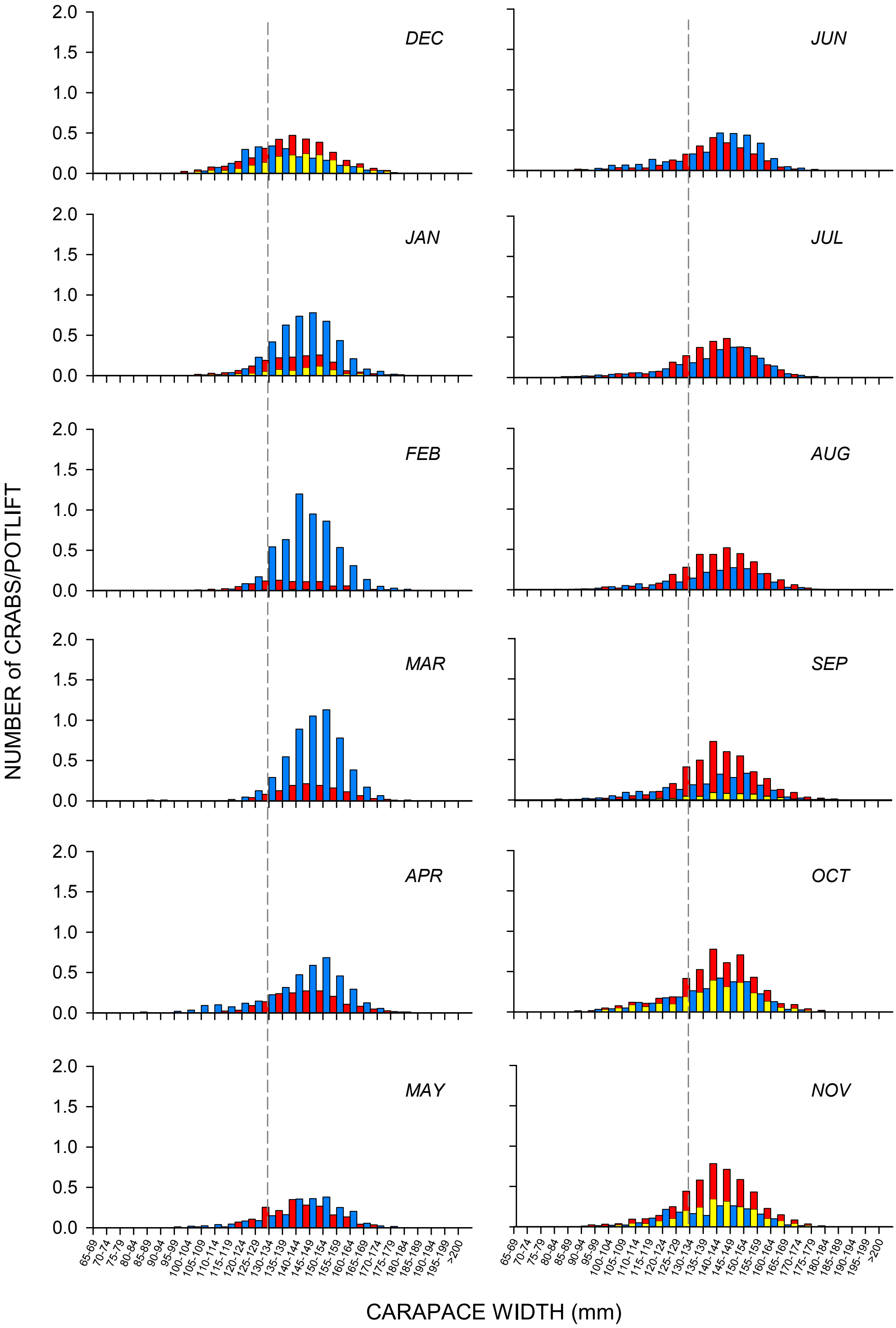


Figure 5.4. Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard commercial vessels in Cockburn Sound during closure between December 2006 and November 2009. Minimum commercial size limit 130 mm CW (- - -).

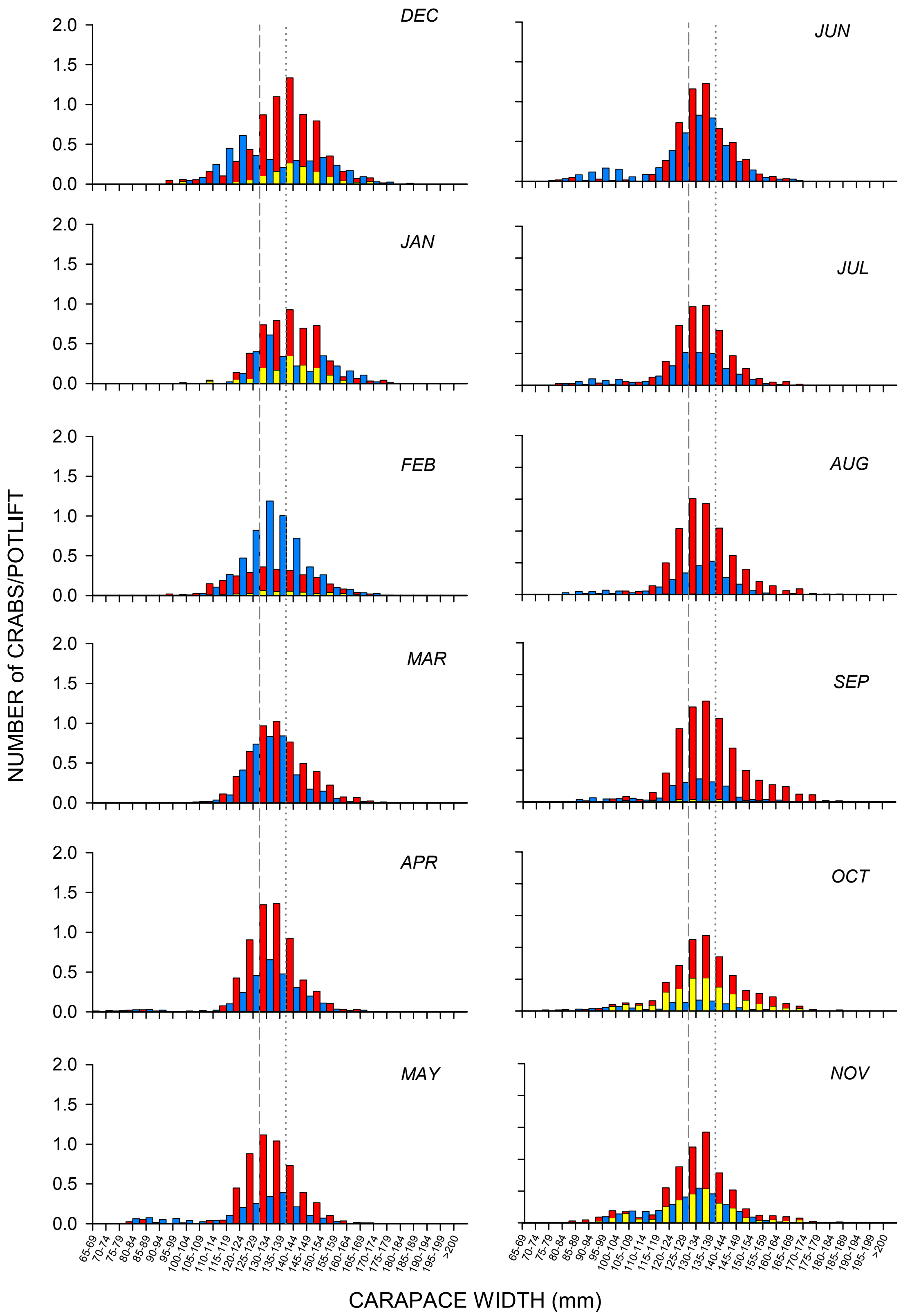


Figure 5.5. Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs from catch monitoring surveys aboard commercial vessels in Cockburn Sound between December 2009 and November 2010 (first season re-opened). Standard minimum commercial size limit of 130mm CW (- - -); minimum commercial size limit for the 2010 season of 140mm CW (·······).

During the 2009/10 season the sex ratio changed again with ovigerous females remaining in the catch later in the season, with large numbers in December (19%) and January (30%) and some present as late as February (14%) (Fig. 5.5). Females dominated the catch for longer during the summer months (January 64% vs 28% pre-closure and February 33% vs 14% pre-closure) with a late switch to males in February followed by an increase in females in March, with females dominating the catch from April onwards (54-72%).

Since the closure, the size of blue swimmer crabs captured in traps has increased significantly. Prior to the closure, the mean size of males and females in the commercial traps during December was 131 mm CW and 134 mm CW, respectively (Fig. 2.4). As the season progressed, mean size increased slightly through to March (136 mm CW for males; 138 mm CW for females) before decreasing by July to 129 mm CW for males and 133 mm CW for females (Fig. 2.4). During the closure, crabs captured in December had a mean carapace width of 136 mm CW and 143 mm CW for males and females, respectively, increasing to 148 mm CW for males and 149 mm CW for females by March. Mean size of males decreased to 141 mm CW and females decreased to 145 mm CW by July (Fig. 5.4). During the 2009/10 season a distinct 1+ and 2+ cohort of male crabs was apparent in length frequencies for the first time in December 2009 and January 2010, presumably due to the absence of fishing for 3 years (Fig. 5.5). Mean size of 1+ males was 121 mm CW versus 140 mm CW for 2+ males in December and 132 mm CW versus 142 mm CW in January. As the season progressed the 2+ cohort was no longer evident as large males were taken out of the fishery. Female size was 140-142 mm CW in December and January, decreasing to 138 mm CW by March due to fishing pressure. A small recruiting cohort is also evident in May-June possibly due to the increased numbers of juveniles evident in the 2010 season (see below). This was also evident in the sampling prior to closure of the fishery (Fig. 2.4). Removal of 140+ mm CW crabs through the 2010 fishing season has reduced the numbers of large crabs sampled during commercial monitoring in the months following closure (April–November) compared with the same period during the 2006-2009 closure (Figs 5.4, 5.5).

5.4.3 Research Trawl Surveys

Research trawl surveys aboard the *RV Naturaliste* in the Research Area site of Cockburn Sound (Fig 5.1) have provided estimates of crab abundance with the mean trawl catch rate ($\pm$ standard error) falling to between 1.2 ± 0.2 and 2.3 ± 0.3 crabs.1000 m^{-2} in 2004-2006 before the fishery was closed. Since the closure the numbers of crabs captured during research trawl surveys increased gradually to 5.5 ± 1.5 crabs.1000 m^{-2} in 2008, declining slightly to 3.0 ± 0.4 crabs.1000 m^{-2} in 2009. Mean trawl catch rate increased significantly to 7.8 ± 0.8 crabs.1000 m^{-2} in 2010, reflecting a marked recovery in the crab population in Cockburn Sound to levels similar to average years pre-closure (2002-2003), but trawl catch rates are not yet at levels recorded in good years (eg. 1999).

5.4.4 Juvenile recruitment - Catch prediction model

Research trawl surveys have been conducted annually since 2002 to collect data on juvenile blue swimmer crab abundance in Cockburn Sound. The juvenile recruitment index developed from the trawl data has then been used for predicting the following season's commercial catch. This juvenile (0+) index developed by Bellchambers et al. (2006) has recently been refined to include a greater number of recruitment areas and a residual stock (1+) component for predicting catches during closure and recovery years (Johnston et al., 2011, Chapter 2). It was recognized that while the six sites covering the middle and northern regions of the Sound provided a reasonable correlation with the strength of recruitment in years of high juvenile abundance, it was possible that these sites were less influential than those in the prime nursery areas of Mangles and Jervois Bays. The model provided a better correlation when data from all 15 Cockburn Sound juvenile trawl sites (3 replicate sites at each of 5 areas Mangles Bay, CBH Jetty, Colpoys Point Jervois Bay and Garden Island North) were included. It was also recognized that the coming season's catch is composed of two year classes. Juveniles from the previous season's spawn recruit to the fishery during autumn to form the bulk of the coming season's catch. However, there is also a (smaller) proportion of the coming season's catch that is made up of the residual stock that did not get caught in the previous fishing season. This second year class was not a significant component during periods of heavy fishing but does make a significant contribution of the stock since the closure and with a more conservative fishing regime. Consequently, we now incorporate both the strength of recruitment (0+) and residual stock (1+) left at the end of the current fishing season (or not been fished at all during closure), in the development of the index used in the catch prediction model (Figs 5.6, 5.7). However the relative contributions from the recruitment and residual components still needs to be assessed as historically the recruitment component dominated the next season's catch as there was little residual abundance.

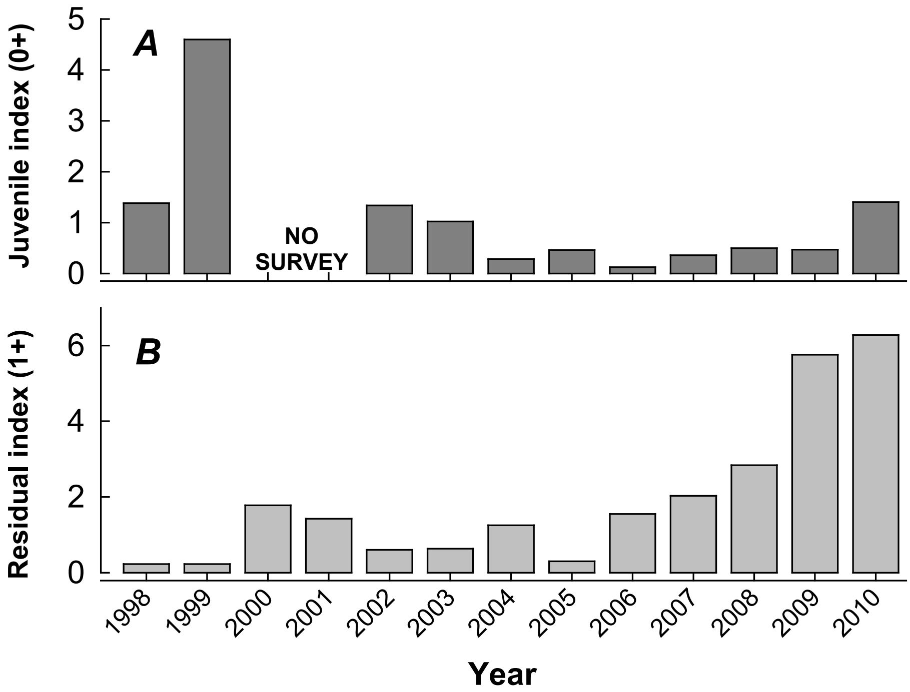


Figure 5.6. Annual standardised indices for blue swimmer crabs in Cockburn Sound of (***A***) juvenile recruitment based on research trawl data collected between April – June at all juvenile recruitment sites; and (***B***) residual abundance based on commercial catch monitoring trap data collected for the months of August and September. No juvenile sampling was conducted in 2000 and 2001.

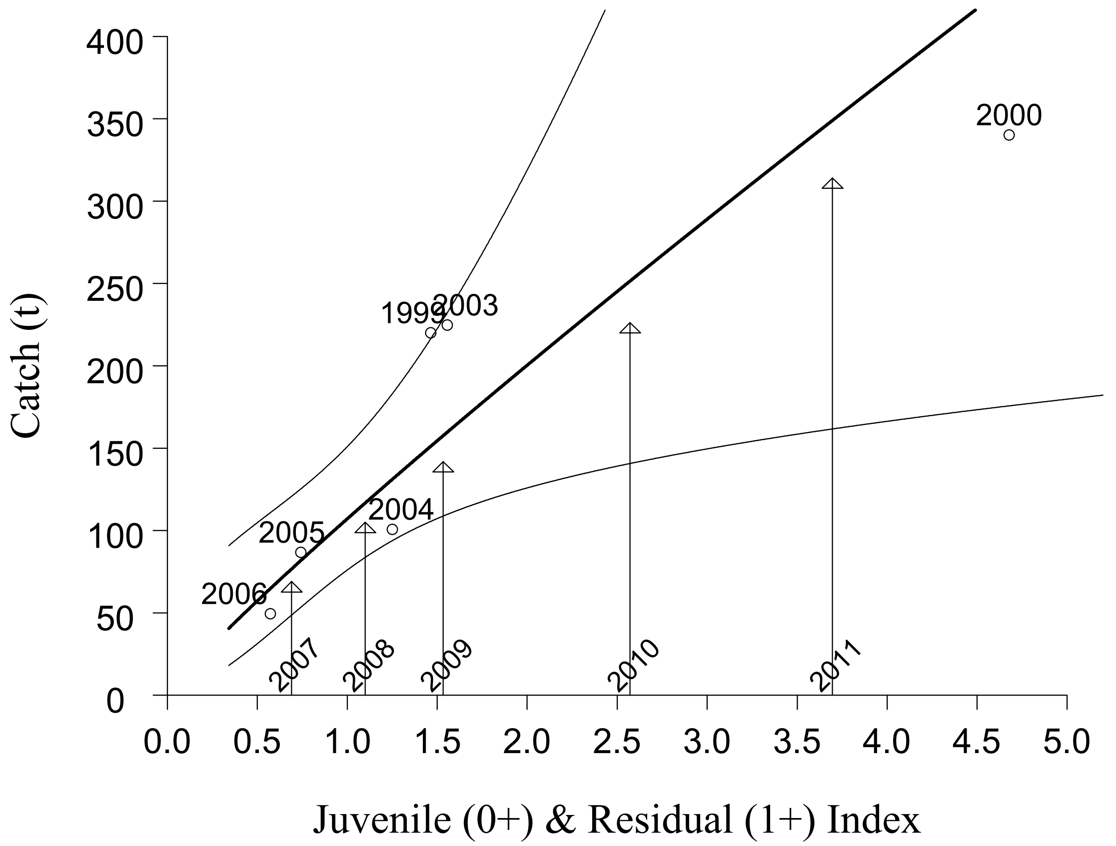


Figure 5.7. The relationship between commercial crab landings and the 0+ (juvenile) and 1+ (residual) index based on data collected from juvenile trawls at all sites sampled in Cockburn Sound between April and August for 0+ (juvenile) and May to August for 1+ (residuals). The commercial catch for each year (○ and labelled with the year of catch) is plotted against the juvenile and residual index from the previous sampling year (e.g. point labelled 2006 represents the commercial catch for the 2006 fishing season (December 05–September 06) plotted against the juvenile and residual index of the previous year of 0.6). The arrows indicate predicted commercial catch for that year if the fishery had opened, based on the previous years juvenile and residual index (2007 predicted catch of 77t based on index of 0.71 from 2006). No data are presented for 1998, 2001 and 2002 as juvenile recruitment surveys were not undertaken in 1997, 2000 or 2001, hence the juvenile index could not be calculated for these years.

Between 1999 and 2006, the juvenile (0+) index fell from 4.4 to just 0.12 (Fig. 5.6). Since closure of the fishery in December 2006, a modest improvement in the strength of recruitment has occurred, increasing to 0.47 in 2009 (Fig. 5.6). In 2010, there has been a large increase in the juvenile index to 1.4 reflecting the large recruiting (0+) cohort that is evident this year in research trawls (Figs 5.6, 5.8, 5.9). During closure (2006-2009), numbers of juveniles at Colpoys Point and CBH Jetty sites increased slowly, with numbers spread evenly between March and August compared to the historical higher abundance pulse between March and May (Fig. 5.8). During 2010, juvenile abundance at these sites has been the highest since the fishery closed in 2006 with numbers in April and June significantly higher than the average number recorded in those months in the years preceding closure (2001-2005). However, variability is high with abundance in March, May and July approximately half that of April and June (Fig. 5.8). Nevertheless, juvenile abundance in Mangles Bay and Jervois Bay showed similarly high levels with peak recruitment occurring in May, indicating a relatively good recovery in juvenile stocks this year.

Although large numbers of juveniles are evident in 2010, the size of recruits is smaller than previous years (Fig. 5.9). This may have implications for commercial fishing in the 2010/11 season with a potentially lower proportion of recruits moulting to a size large enough to be captured at the new legal size of 140 mm CW and during the season (if it remains December to March). It is possible that cooler than average water temperatures in Cockburn Sound during traditional spawning months of September and October in 2009, may have resulted in a later spawning period contributing to the smaller sized juvenile cohort in 2010 (Fig. 5.10). The mean August and September water temperature recorded in Warnbro Sound is also much lower than the historical average for these months also indicating that spawning may have been delayed in 2009 (Fig. 5.11).

Recovery in juvenile recruitment has differed spatially throughout Cockburn Sound. In 2007 numbers of juveniles were low in all sites trawled (Fig. 5.12). Between 2008 and 2010, recruitment was most successful in the inshore shallow areas of Jervois Bay, James Point and Mangles Bay in the East and South of the Sound, with numbers of juveniles increasing more quickly than at Garden Island, Woodman Point and Owen Anchorage. In contrast, the gradual recovery of the breeding stock has largely been consistent throughout Cockburn Sound. Numbers of mature, large (1+) ovigerous female crabs increased steadily at all seven trawl sites between 2007 and 2009 (Fig. 5.9, 5.13). But while there was a further increase in quantities of ovigerous 0+ females at Jervois Bay and Garden Island South in the 2010 survey, there was a marked reduction in numbers of larger 1+ animals at all seven sites (Fig. 5.9, 5.13).

A catch prediction model incorporating both the strength of recruitment and the residual stock remaining towards the end of the commercial season has been used to predict potential commercial catch during closure of the fishery (assuming a similar level of effort is maintained) as a tool to assess its recovery (R^2 = 0.83) (Fig. 5.7). After a commercial catch of 50 t in the Cockburn Sound crab fishery for 2006, the 2006 juvenile and residual index of 0.61 predicted commercial catch of just 77 t for the 2007 fishing season. Indicative of the gradual recovery of the Cockburn Sound crab stock, the juvenile and residual indices for 2007 (1.1), 2008 (1.5) and 2009 (2.6) predicted potential commercial catches of 113, 156 and 220 t for the 2008, 2009 and 2010 seasons, respectively (Fig. 5.7). The improved 2010 catch prediction was one of the contributing factors to recommending a precautionary partial opening of the fishery under strict conditions (see Decision-rule framework in section 5.3). A preliminary estimate of the 2010 juvenile and residual index of 3.7 has predicted a commercial catch of 349 t for the 2011 season. However a significant contribution to this catch is the residual biomass and there is little historical information to use as a basis for estimating its contribution.

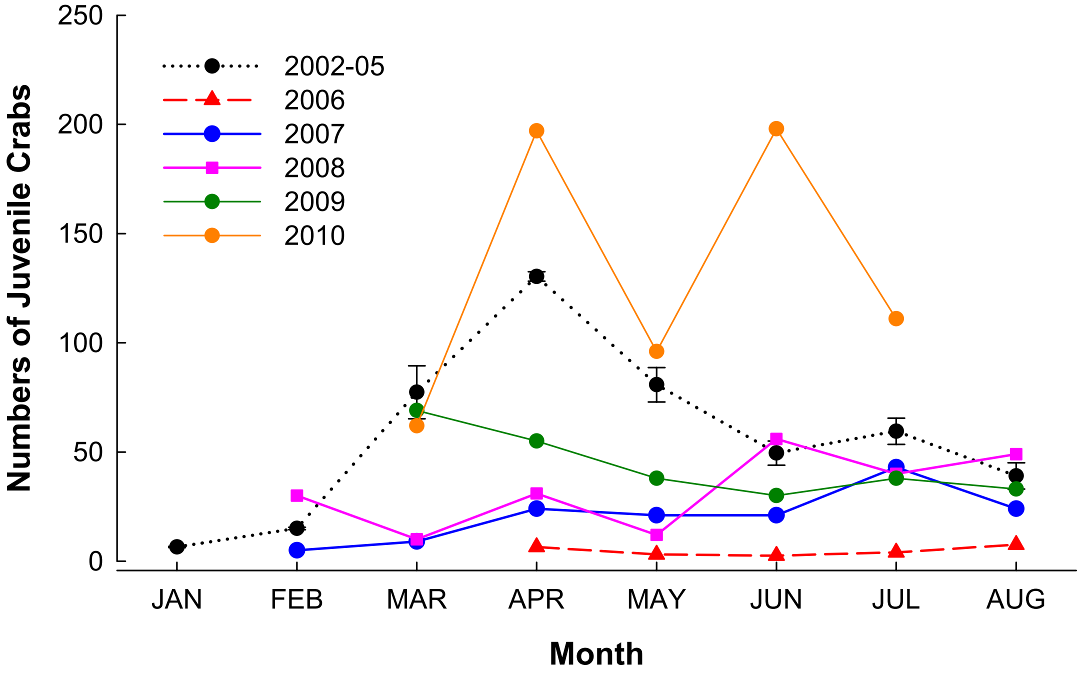


Figure 5.8. Total number of juvenile (0+) blue swimmer crabs captured during monthly trawls at 3 replicate sites at the CBH Jetty and 3 replicate sites Colpoy's Point in Cockburn Sound. Data between 2002 and 2005 was averaged per month.

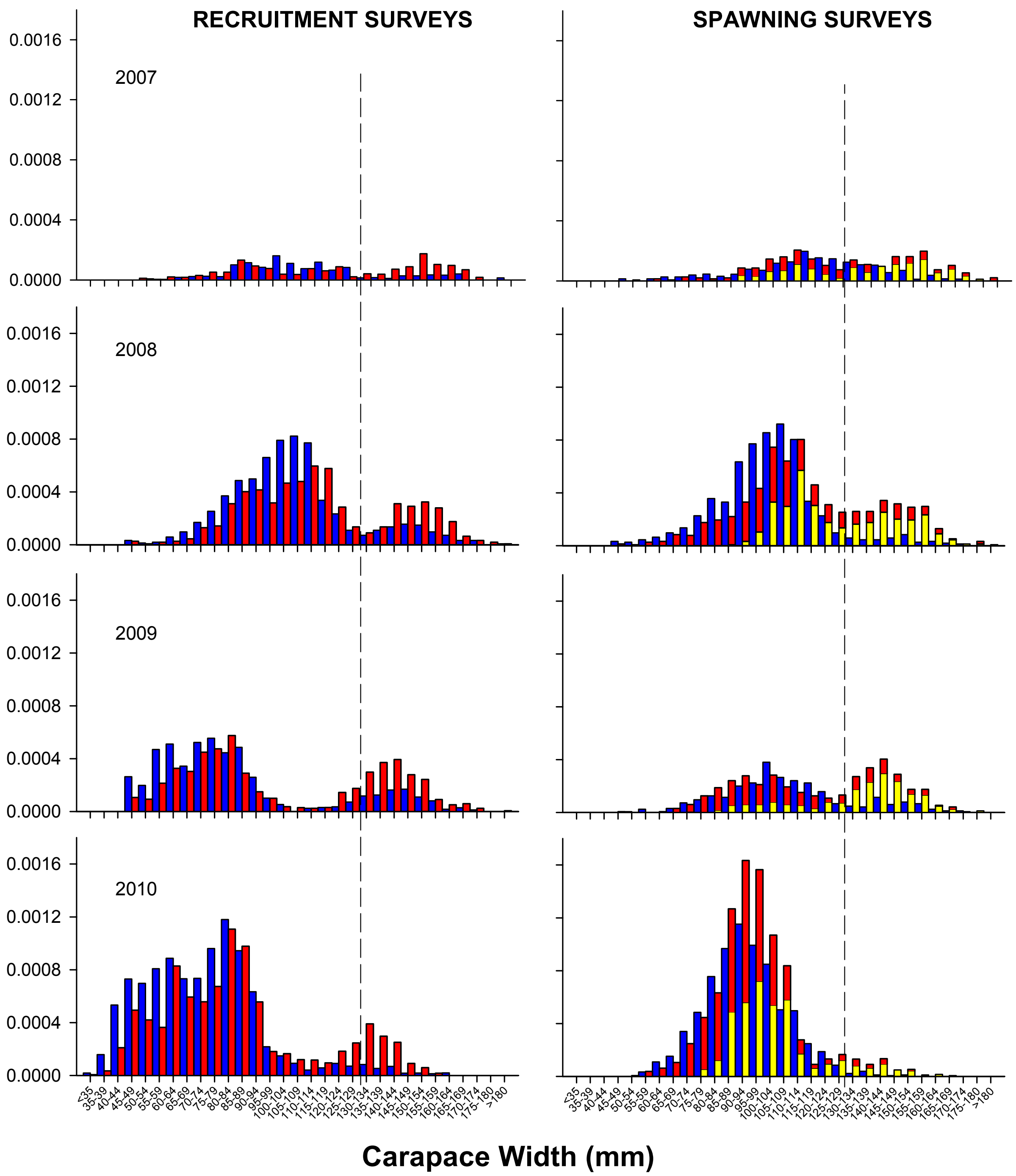


Figure 5.9. Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs captured during recruitment (April/May) and spawning (October/December) trawl surveys aboard *RV Naturaliste* at all sites in Cockburn Sound between 2007 and 2010. Standard minimum commercial size limit of 130mm CW(- - -).

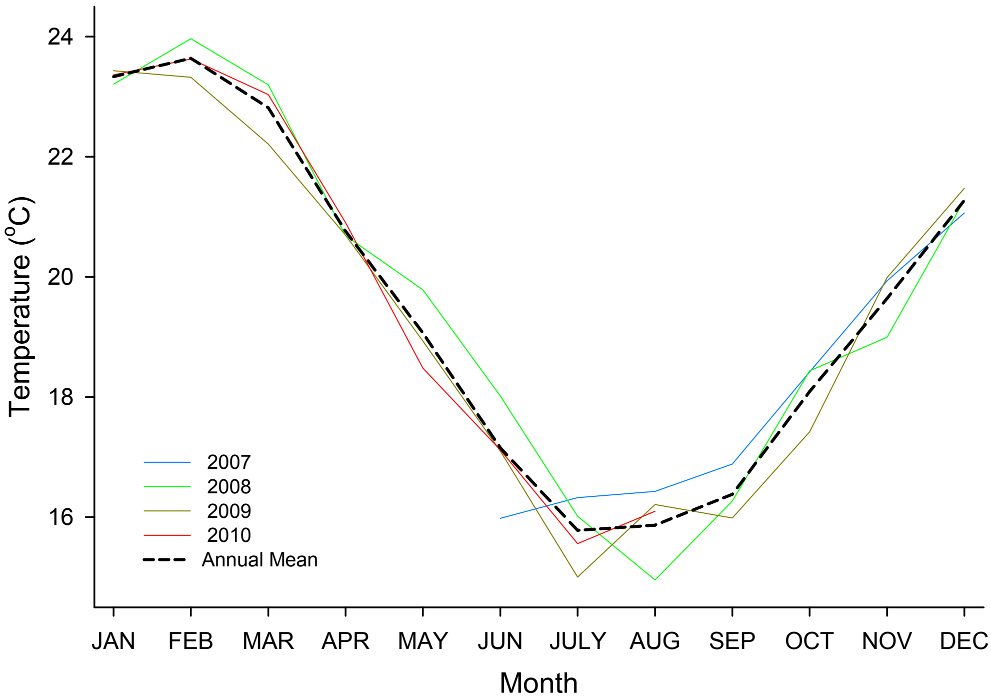


Figure 5.10. Mean monthly water temperatures recorded by Dataflow temperature loggers at five locations around Cockburn Sound between June 2007 and June 2010 inclusive.

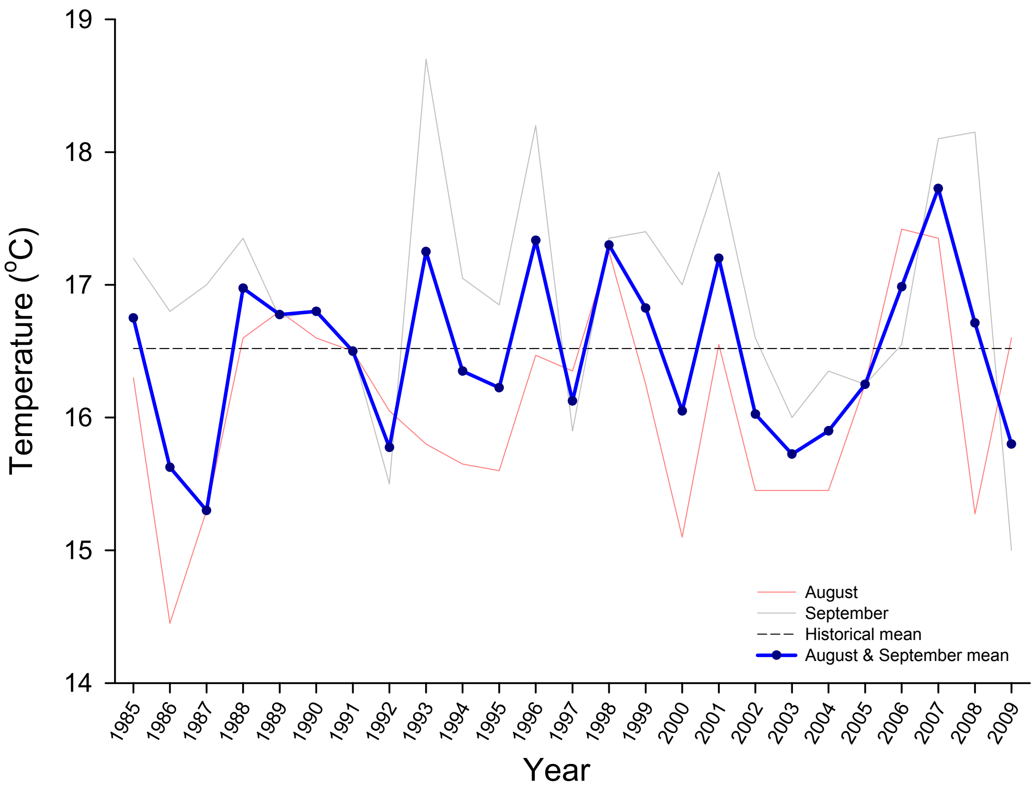


Figure 5.11. Mean annual water temperatures for August-September recorded in Warnbro Sound for the period 1985 to 2009. Individual mean temperatures for August and September, along with the historical mean of August-September water temperature (16.6ºC), are also indicated.

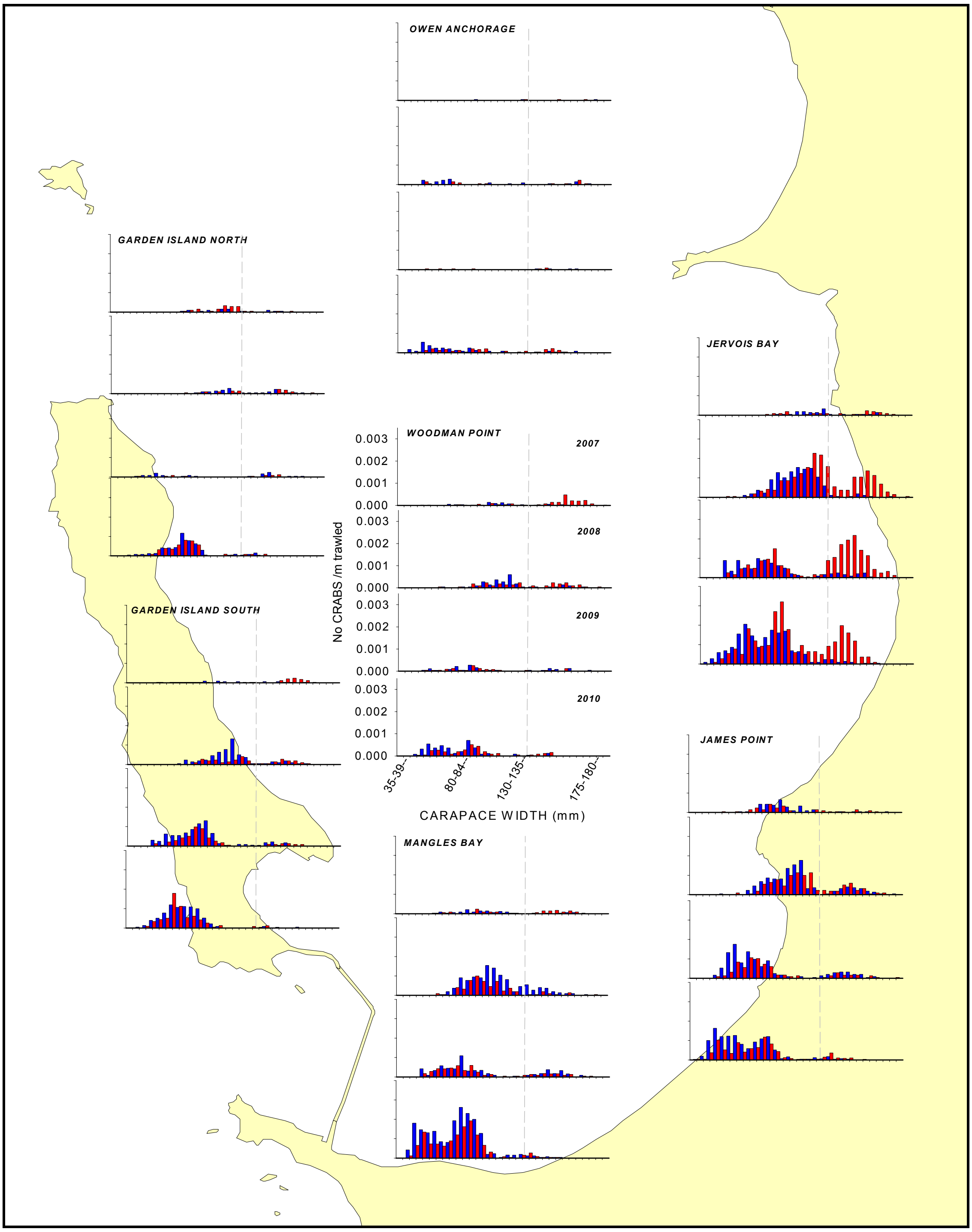


Figure 5.12. Length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs captured during recruitment (April/May) trawl surveys aboard *RV Naturaliste* in Cockburn Sound between 2007 and 2010. Standard minimum commercial size limit of 130mm CW(- - -).

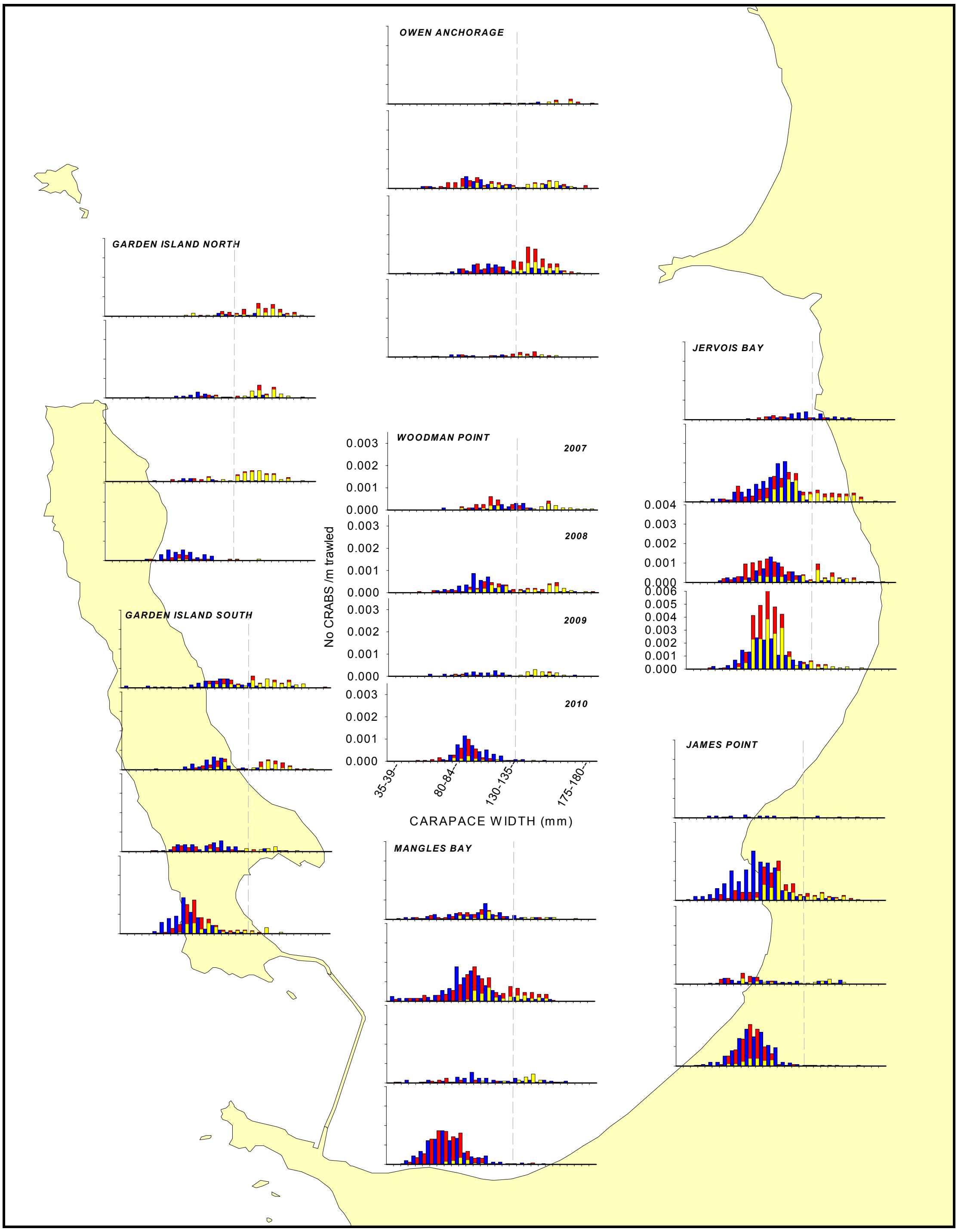


Figure 5.13. Length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs captured during spawning (Nov/Dec) trawl surveys aboard *RV Naturaliste* in Cockburn Sound between 2007 and 2010. Standard minimum commercial size limit of 130 mm CW(- - -).

5.4.5 Egg Production

Historically, the Cockburn Sound crab fishery was managed by setting a recreational and commercial minimum size (127 and 130 mm CW, respectively) well above the size at sexual maturity (86-96 mm CW) to allow crabs to spawn at least once before entering the fishery. However, this measure failed to provide sufficient protection to the female breeding stock as periods of low recruitment (due to successive years of low water temperature) combined with heavy fishing pressure in the pre-spawn months over winter led to the collapse of the fishery (see Johnston et al., Chapter 2 for details of factors contributing to the collapse). It is therefore important to examine ways of protecting the breeding stock and allowing a minimum level of stock to always be available.

A breeding stock (egg production) index has been developed using data from the commercial monitoring program, trawling aboard the Department of Fisheries research trawler *RV Naturaliste*, and the juvenile trawl program (see de Lestang et al. 2010, Chapter 3 for detailed description). The breeding stock in 2006/07 was poor due to the low abundance of juveniles in 2006 (see Fig 5.6, 5.8). Despite a small improvement in the juvenile (0+) abundance and improved residual (1+) abundance in 2007 (as a result of the closure in the 2006/07 season), breeding stock abundance as measured by the egg production index remained low in 2007/08 (Fig. 5.14). Juvenile (0+) and residual (1+) abundance improved in 2008 (Figs 5.6, 5.8) leading to an increase in breeding stock (egg production index) in 2008/09 (Figs 5.8, 5.14). A similar level of juvenile (0+) and improved residual (1+) abundance in 2009 (Figs 5.5, 5.8) lead to a further improvement in breeding stock as indicated by the increase in egg production index in 2009/10 (Fig. 5.14). The marked increase in juvenile and residual abundance in 2010 (Figs 5.5, 5.8) suggests that the breeding stock levels in 2010/11 should be maintained at levels obtained in productive years prior to closure (Fig. 5.14).

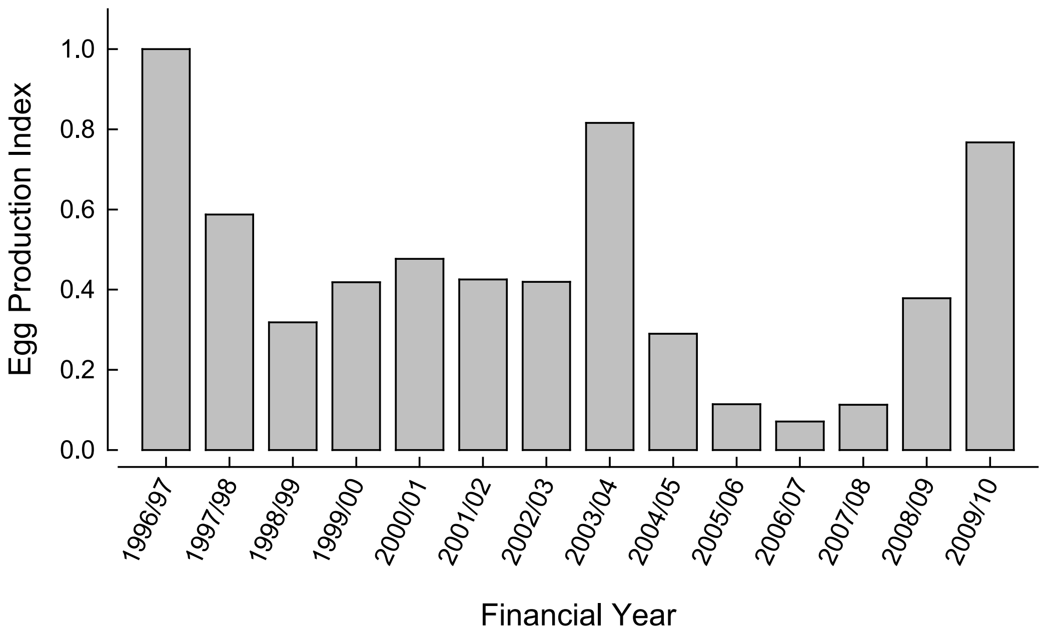


Figure 5.14. Annual standardized egg production index based on numbers and carapace widths of sexually mature female blue swimmer crabs captured during juvenile trawl surveys (1996-1999), trawl surveys aboard the Fisheries Research trawlers *RV Flinders* (1999–2001) and *RV Naturaliste* (2001-2010), and catch monitoring surveys aboard commercial crab vessels in Cockburn Sound.

5.4.6 Stock-recruitment-environment relationship

A preliminary stock-recruitment-environment relationship was determined for the Cockburn Sound crab fishery (Fig. 5.15) as a possible explanation of the recruitment decline (see de Lestang et al., 2010, Chapter 3). The relationship is based on the abundance of the breeding stock (Egg Production Index) over the summer (year t/t+1), the subsequent season's commercial catch (year t+1/t+2) and the average water temperature (from Warnbro Sound puerulus monitoring) before the onset of spawning (August-September year t). Predicted catches during the closed seasons were based on juvenile abundance only to reflect that previous season's catches were generally based on the juvenile recruitment class with little contribution from residuals (2+). The relationship indicates that temperature and egg production index significantly influence the level of recruitment and catch in the following year. The long-term trend in water temperature indicates that there has been only one four-year series of below average temperatures, 2002-2005 (Fig. 5.11) that may have contributed to the series of low recruitment in this period.

The initial reduction in catch in 2003/04 and 2004/05 appears to be mainly due to the environmental conditions (low water temperatures in 2002 and 2003), as the spawning stocks in the previous years (2002/03 and 2003/04) were at moderate levels (Figs 5.11, 5.14).

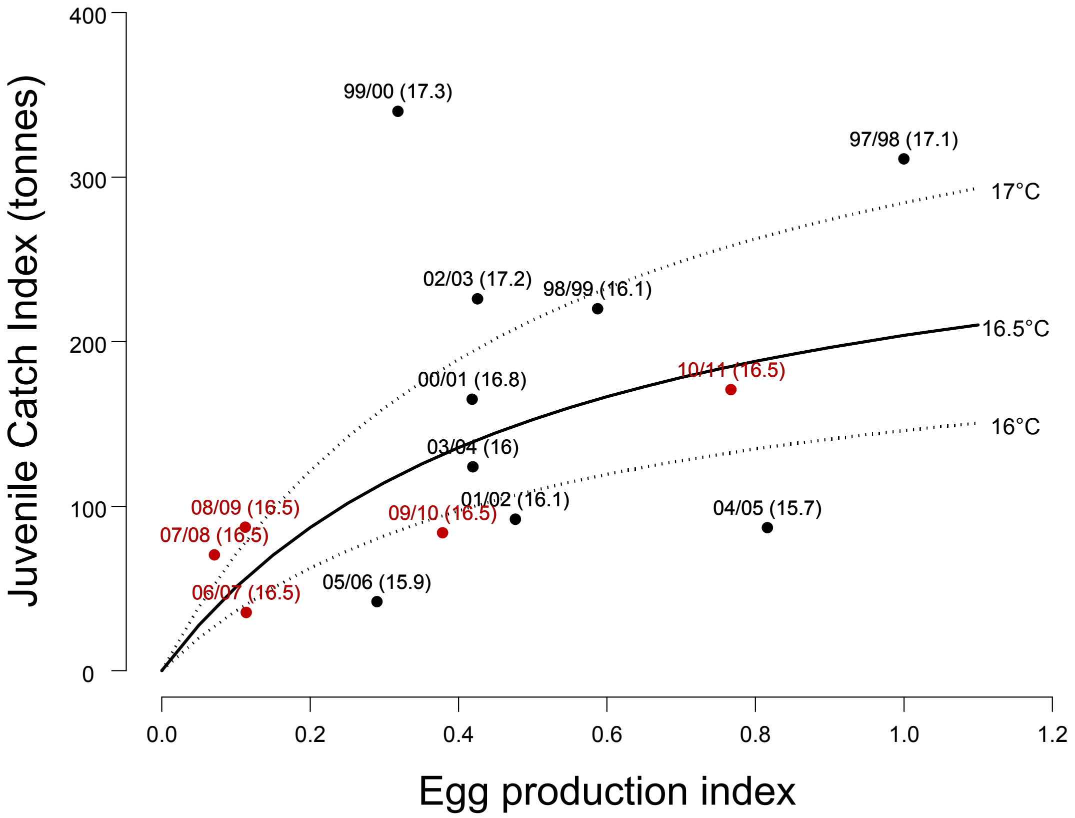


Fig. 5.15. Beverton and Holt stock-recruitment relationship between commercial catch or predicted catch based on the juvenile (0+) index and egg production (preceding season) at three different water temperatures (mean August/September), i.e. 16.0, 16.5 and 17.0ºC. The year (fishing season) and the mean temperature during the preceding August and September (in parentheses) are indicated. Predicted commercial catches based on the juvenile 0+ index for the 2006/07, 2007/08, 2008/09, 2009/10 and 2010/11 seasons are indicated in red. Predicted commercial catch based on the juvenile index only are as follows: 06/07 35t; 07/08 71 t; 08/09 87 t; 09/10 84 t; 10/11 171 t.

The low recruitment to the fishery in 2004/05, combined with fishing pressure, resulted in low levels of egg production in 2004/05 (Fig. 5.14). The subsequently low catch observed in 2005/06 was caused by the combination of low egg production and continued below average water temperatures in the pre-spawn period. Following closure of the fishery, recruitment has gradually improved, and egg production has also improved. This gradual recovery of stocks has been aided by two successive years of above average water temperature in August-September 2006 and 2007 (Fig. 5.11). However, despite an improved breeding stock in 2008/09, the water temperatures in August-September 2008 were average which may have been responsible for a similar level of juvenile (0+) abundance index in 2009 (Figs 5.6, 5.9). August and September in 2009 were also colder than average resulting in a higher proportion of smaller crabs in the 2010 recruiting cohort (Figs 5.9, 5.11). However the egg production index in 2009/10 had improved resulting in a very good overall juvenile 0+ recruitment in 2010 (Figs 5.6, 5.8, 5.9).

If the stock-recruitment-environment relationship provides a correct representation of the stock dynamics then it is important to ensure that egg production is maintained at levels above an index of about 0.5 (Figs 5.14, 5.15). Above this threshold level, the recruitment appears to be mainly affected by the environmental conditions. The egg production index of 2009/10 (~0.8) meets this criterion, suggesting for the first time since closure of the fishery that the breeding stock levels may be adequate.

Genetic studies have indicated that while the population of blue swimmer crabs in Cockburn Sound is generally independent from other stocks around the state, there is some level of inter-relatedness between the Cockburn Sound crab stock and stocks in Warnbro Sound and the Swan River (Chaplin et al., 2008, Chapter 4). The studies were unable, however, to determine the nature of the inter-relatedness that exists i.e. larval exchange due to water current, wind and tidal movement as compared to migration of juvenile or adult stocks. Following the precautionary principle, therefore, we continue to work under the premise that strengthening the recruitment of crabs in Cockburn Sound is still dependent on rebuilding the spawning stock in the Sound.

5.5 Decision Rule Framework - Management

A draft decision-rule framework for the management of the Cockburn Sound crab fishery has been developed that uses biological reference points to determine the appropriate level of fishing for the coming season (Fig. 5.16, see also Johnston et al. 2011, Chapter 2 for details).

A linear model incorporates commercial monthly catch distribution and the annual juvenile and residual index derived for the Cockburn Sound crab fishery catch prediction model (Fig. 5.7) to set an appropriate length for the commercial season. By the end of January, for example, 30% of the predicted catch for that season would have been taken (assuming the season ends in June), leaving 70 % of that catch unexploited (Fig. 5.16). For years when the juvenile and residual index is relatively low (1.6 to 2.6), the length of season can be manipulated to ensure an adequate proportion of the crab biomass will remain unfished to provide a further buffer for spawning stocks (additional egg production). If the annual index is below a prescribed level (for example ≤1.6), the fishery will be closed as the predicted catch will be ≤150 t under the previous levels of fishing (Fig. 5.16). However, if the annual index is above a prescribed safe level (for example >3.5), the fishery may be fully opened to June as the predicted catch would be about 300-350 t under the previous levels of fishing (Fig. 5.16).

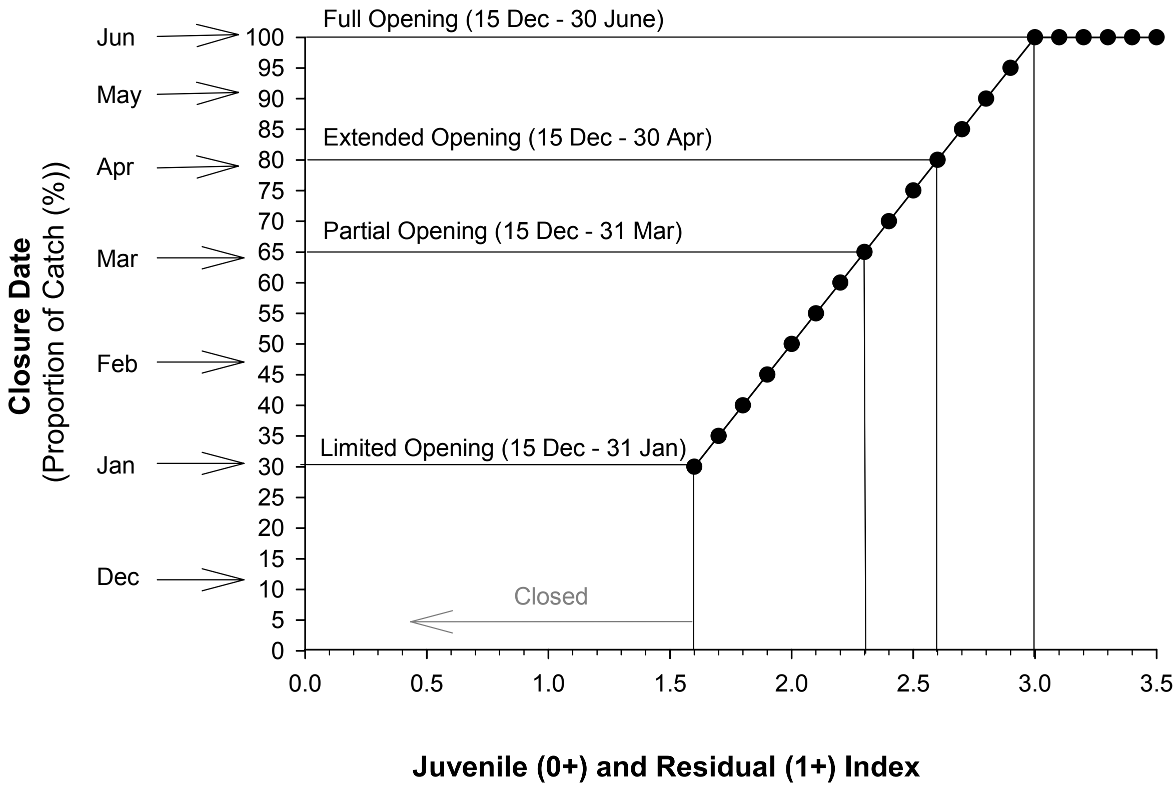


Figure 5.16. Draft decision-rule framework for the Cockburn Sound Crab Managed Fishery that incorporates both the strength of recruitment (juvenile 0+) from the previous season's spawn (September to January), and the residual stock (1+) remaining in the water towards the completion of the current fishing season, to estimate the percentage of catch taken per month over a season.

Future management arrangements for this fishery will limit the level of fishing effort in winter months to protect the mated pre-spawning females and provide a buffer to breeding stock. The ratio of males to females historically changes from predominantly males between January and March to females between April and September, so fishing effort will be reduced in months when females dominate the catch in order to increase egg production. The level of predicted catch to be fished within the specified time frame by the commercial and recreational sectors will also be controlled by minimum size and effort (trap number) restrictions.

Under this framework, the fishery remained closed during the 2006/07 season as the juvenile and residual index for 2006 was just 0.61 (catch prediction 77 t). The 2007 index of 1.1 (113 t) and 2008 index of 1.5 (156 t) were again at or below the index threshold of 1.6, so the fishery remained closed during the 2007/08 and 2008/09 fishing seasons (Fig. 5.16). The 2009 juvenile and residual index however was much higher at 2.6 (catch prediction of 220 t) and the fishery was re-opened under a strict management regime. Based on the decision rule framework the fishery was opened for a limited season between 15 December and 31 March allowing approximately 60% of the predicted catch of 220 t to be harvested. However further restrictions of a 20% trap reduction and increased minimum size (140 mm CW) were implemented to help protect breeding stock and reduce the amount of catch taken. This commercial catch for the 2009/10 season was 56 t.

5.6 Management advice

The preliminary 2010 juvenile and residual index of 3.7 and predicted commercial catch of 349 t indicates that the crab population has improved further and justifies, along with the improvement in egg production, that the fishery can be re-opened for the 2010/11 season. However, the fishery is still recovering so a precautionary approach to management is recommended. Options should be reassessed annually after analysis of available data. Note that the impact of recreational fishing on the fishery is not known at this time (analysis of data required).

The 2009/10 management arrangements, and their justifications are as follows:

1. Season length of 3.5 months between 15 December 2009 and 31 March 2010. This allowed moderate catch levels for both sectors whilst providing some protection for female brood stock as both sectors traditionally catch mainly male crabs during summer months. Irrespective of the status of stocks, winter fishing in the future should be avoided (July-September) to protect the female breeding stock.
2. Increased minimum size to 140 mm CW for the commercial sector (and 127 mm CW remaining for the recreational sector). This option provided significant protection to both males and females, as it prevented the capture of 50-60 % of stock in fished conditions with good recruitment or 15-34 % in unfished conditions with current levels of poor recruitment, between December and March. It allowed females greater potential to spawn more than once before entering the fishery. It also increased the value of catch by increasing the dollar value per kg, improving economic performance of the fishery. In the longer term, however, the large discrepancy between the recreational minimum size limit of 127 mm CW will need to be addressed and the adoption of a commercial vs. recreational sector minimum size across all southwest fisheries should be considered.
3. Effort reduction of 20%. This conservative reduction in trap numbers did not have a significant impact on catch during the 2009/10 season with data suggesting that this level of effort reduction absorbed the existing amount of latent effort in the fishery during normal fishing years prior to closure.

Given the recovery in breeding stock and juvenile recruitment this year and the good residual abundance being maintained, possible amendments to this set of management conditions for the 2010/11 season include:

1. Reducing the minimum size for the commercial sector from 140 mm CW to 135 mm CW to allow a greater proportion of recruitment to be taken (whilst maintaining the season at 15 December to 31 March). This option would focus mainly on males over the summer months. Note that although large numbers of juveniles are evident in 2010, the size of recruits is smaller than previous years. This option is preferred for the 2010/11 season with a potentially lower proportion of recruits moulting to a size large enough to be captured at the size of 140 mm CW.

2. Extension of season length by 1 or 2 months from 15 December 2010 to 30 April 2011 or 31 May 2011 (whilst maintaining a minimum size of 140 mm CW). According to the Decision Rule Framework it is possible that a further extension to June 30, 2011, may also be considered given the current increase in juvenile and residual index. However, there is the risk of potentially targeting a greater number of females. Historically, from April onwards the sex ratio of commercial catch changes from males to females and this was also the case in April during the recent 2009/10 season (Fig 5.5). So it is important to take a precautionary approach with respect to season length in order to protect the breeding stock.
3. A combination of reducing the minimum size from 140 mm CW to 135 mm CW and an extension of season length by 1 month from December 15, 2010 to April 30, 2011. If this option were chosen a further 20% trap reduction would be imposed to reduce effort (40% reduction in total from original 800 traps).

After consultation with RecFishWest and WAFIC and advice from the Department, the Minister decided to reduce the commercial size limit from 140 mm CW to 135mm CW and maintain the same season length between 15 December 2010 and 30 March 2011 (option 1). This was the preferred option for the commercial fishers. The recreational fishing season was increased by 1 month to the end of April to provide some compensation for the anticipated increased catch share by the commercial fishers at 135 mm CW. The recreational size limit remains unchanged at 127 mm CW.

6.0 Future Research

Experience gained from the stock collapse in Cockburn Sound has increased our understanding of the biology and management of blue swimmer crab fisheries, particularly in temperate locations like the south-west of Western Australia where this species is at the southern extreme of its distribution. Information gained during this project will be beneficial in determining the way that blue swimmer crab fisheries are managed in Cockburn Sound and elsewhere in the State in the future. Suggested areas for monitoring and research in Cockburn Sound and Warnbro include:

Cockburn Sound

1. Refine the research juvenile trawling program temporally and spatially to target key months and recruitment sites each year. Update the juvenile (0+) and residual (1+) index and catch prediction model on an annual basis to predict the next season's commercial catch. Statistical analyses will be conducted to determine the key months and sites.
2. Refine the research trawling program on the *R.V. Naturaliste* to target key recruitment and breeding stock sites and reduce sampling from 2 nights to 1 night per recruitment and spawning period. Examine densities of all age classes of blue swimmer crabs to assess recruitment and spawning stock status annually.
3. Refine monthly catch monitoring on commercial vessels during open and closed seasons from twice to once per month due to the consistency of monthly length frequency data between years. This provides a comparison with previous commercial and research data to assess the strength of the recruiting cohort and spawning stock.
4. Review the egg production index annually using commercial monitoring and *RV Naturaliste* data to update the stock-recruitment-environment relationship.
5. Based on the strength of the recruiting (0+) cohort, residual (1+) abundance and breeding stock status each year, use the decision-rule framework to provide research advice on appropriate management regulations for each future season.
6. Use recreational data from the annual West Coast survey funded using the Recreational Fishing From Boat licence fees to provide basic information on recreational crab catch and effort.

Warnbro Sound and Swan River

1. Continue commercial monitoring to assess length frequencies, sex ratio and berried female status of crabs in Warnbro Sound and Swan River. Depending on data available assess strength of recruiting cohort and breeding stock (although in Swan River berried females and juveniles are not present in commercial nets).

7.0 Acknowledgements

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9.0 Appendix 1

Recreational Crabbing in Cockburn Sound

9.1 Recreational Catch

Recreational catch and effort in Cockburn Sound is dominated by boat-based fishers, with shore-based activity considered to be negligible (Sumner and Malseed, 2004). Approximately 75% of recreational crabbing effort was found to occur during the summer months of January to March. Recreational surveys have been conducted in Cockburn Sound in 1996/97 (Sumner and Williamson, 1999), 2001/02 (Sumner and Malseed, 2004) and January-March in 2003 and 2004 (Bellchambers *et al*., 2005a). The estimated recreational catch of blue swimmer crabs was 18.8 t in 1996/97, representing 5% of the total crab catch in Cockburn Sound (Sumner and Williamson, 1999). A repeat of the 1996/97 creel survey was conducted between September 2001 and August 2002 and provided a boat based recreational catch estimate for Cockburn Sound during 2001/02 of 18.2 tonnes, representing 15% of the total catch (Sumner and Malseed, 2004). A total of 338, 374 and 680 interviews were conducted at five surveyed boat ramps in Cockburn Sound between January and March in 2002, 2003 and 2004, respectively. These surveys were used to estimate annual recreational catches in the range of 18-23 t with the increase in catch in 2002/03 (Table 9.1) reflecting the increase in commercial catch in the same year . Although recreational catch had been relatively constant between 1996/97 and 2004, recreational catch for 2005/06 declined significantly to 3 t (Sumner, unpublished data). This was consistent with the significant decline in commercial catch in this year and resulted in closure of the fishery in December 2006.

Table 9.1. Annual catch estimates (tonnes) of blue swimmer crabs taken by recreational fishers in Cockburn Sound. * 12 month creel survey September – August: 1996/97 - Sumner and Williamson, 1999, 2001/02- Sumner and Malseed, 2004; ** 3 month creel survey over the peak recreational crabbing period from January to March and extrapolated for that calendar year, Bellchambers *et al*., 2005a; ***12 month creel survey financial year, Sumner unpublished data.

Year of Creel Survey	Catch - tonnes
1996/97*	18.8
2001/02*	18.2
2003**	23.0
2004**	18.4
2005/06***	3.0

9.2 Recreational Effort

Between January and March 2002, surveyed recreational fishers in Cockburn Sound targeted blue swimmer crabs for 19,826 hours, spread over a combined 14,263 fisher days. Each crabbing trip averaged 3.49 fisher hours, and involved 2.51 crabbers (Table 9.2). Extrapolation of these estimates provided for a recreational crabbing effort of 19,134 fisher days for the 2002 calendar year. Recreational fishers targeted blue swimmer crabs for a similar amount of time between

January and March 2003. An estimated 19,725 hours was spread over just, 11,876 days however, increasing the average crabbing trip to 3.84 fisher hours. The average size of a crabbing party in 2003 fell to 2.31 crabbers (Table 9.2). These estimates provide for a recreational crabbing effort of 15,932 days for the 2003 calendar year, 17% down on 2002.

Effort remained reasonably constant in 2004, with recreational crabbers fishing for an estimated 18,466 hours over 12,058 fisher days in the January to March period. The average crabbing trip for the year lasted 3.78 fisher hours and involved 2.47 crabbers. Extrapolation of these estimates provides for a recreational crabbing effort of 16,176 fisher days for the 2004 calendar year (Table 9.2).

Table 9.2. Recreational blue swimmer effort in Cockburn Sound for 2002 - 2004. (2001/02 data from boat ramp surveys conducted by Sumner and Malseed (2004); 2003, 2004 data - Bellchambers *et al.*, 2005a)

	2001/02	2003	2004
Average number in party (fishers)	2.51	2.31	2.47
Ave. effort of crabbing trip (fisher hours)	3.49	3.84	3.78
Number of fisher hours January – March	19,826	19,725	18,466
Number of fisher days January - March	14,263	11,876	12, 058
Number of fisher days whole year	19,134	15, 932	16,176

9.3 Sex ratio

Of the blue swimmer crabs caught by recreational fishers during surveys between January and March of 2002, 2003 and 2004, between 94.1% and 98.3% of retained catches were male. During 2004, surveyed fishers caught slightly more blue swimmer crabs than the previous year, with the proportion of female crabs increasing to 5.9%. Overall, the proportion of released males was lower (71.4 – 85.3%) with a higher proportion of females released (14.7 - 28.6 %). A higher proportion of crabs were released in 2004 (44.5%) compared with previous years (Table 9.3). The catch rate of crabs kept/boat/trip in 2002 was 11.1, increasing to 15.8 in 2003 but declining to 12.6 in 2004 (Table 9.3).

Between January and March 2002 – 2004, females comprised 43 – 47% of commercial catches compared to 5 – 16% of estimated annual recreational catches (retained and non-retained) (Table 9.3). These differences are due primarily to spatial separation of fishing between the sectors with recreational fishers favouring the shallow waters of Mangles Bay, the inside of Garden Island and north of Woodman Point, while commercial fishing is spread throughout Cockburn Sound. The sex ratio of crabs in Cockburn Sound displays a seasonal pattern with females comprising 65% of recreational catches in April to June, 75% from July to September and 80% during December (Sumner and Malseed, 2004).

Table 9.3. Numbers of blue swimmer crabs recorded from surveys of recreational boat-based fishers at five boat ramps in Cockburn Sound between January and March 2002-2004. (2002 data from boat ramp surveys conducted by Sumner and Malseed (2004); 2003, 2004 data - Bellchambers *et al*., 2005a)

		2002		2003		2004	
		Number	**%**	**Number**	**%**	**Number**	**%**
Retained	Male	1,016	98.3	1,962	98.7	1,936	94.1
	Female	18	1.7	26	1.3	121	5.9
	Total	**1,034**		**1,988**		**2,057**	
Released	Male	266	85.3	1,005	83.3	1,176	71.4
	Female	46	14.7	202	16.7	472	28.6
	Total	**312**		**1,207**		**1,648**	
% released		23.2		37.8		44.5	
Catch rate							
(crabs kept/boat/trip)		11.1		15.8		12.6	

The estimated total numbers of blue swimmer crabs that were retained in 2002 were 77,300 (18 t) (Table 9.4). These numbers increased to 96,388 (23 t) in 2003, before decreasing to 75,322 crabs (18 t) in 2004 (Table 9.4).

Table 9.4. Annual estimated recreational blue swimmer catch in Cockburn Sound for 2002 - 2004. Weight recorded in tonnes. (2002 data from boat ramp surveys conducted by Sumner and Malseed (2004); 2003, 2004 data - Bellchambers *et al*., 2005a)

		2002		2003		2004	
		Number	**Weight (t)**	**Number**	**Weight**	**Number**	**Weight**
Retained	Male	75,954	17.9	95,127	22.6	70,891	17.5
	Female	1,346	0.3	1,261	0.3	4,431	0.9
	TOTAL	**77,300**	**18.2**	**96,388**	**22.9**	**75,322**	**18.4**
Released	Male	19,012		46,586		39,886	
	Female	3,288		9,363		16,009	
	TOTAL	**22,300**		**55,949**		**55,895**	

9.4 Size distribution

The mean carapace width of male crabs surveyed between 2002 and 2004 was fairly constant, ranging between 137 and 138 mm CW. Females were slightly larger (136-154 mm CW) with size varying to a greater extent between years, mostly due to smaller sample sizes (Table 9.5).

Table 9.5. Mean length of blue swimmer crabs caught by recreational fishers interviewed at boat ramps in Cockburn Sound between January and March, 2002 – 2004. (2002 data from boat ramp surveys conducted by Sumner and Malseed (2004); 2003, 2004 data - Bellchambers *et al*., 2005a)

	MALE			FEMALE			
	NUMBER	%	CW	NUMBER	%	CW	TOTAL
2002	410	98.5	137	6	1.5	140	416
2003	434	99.1	137	4	0.9	154	438
2004	517	93.0	138	39	7.0	136	556
TOTAL	**1361**	**96.5**	**137**	**49**	**3.5**	**138**	**1410**

9.5 Cockburn Sound recreational blue swimmer crab survey - 2009/10 season

Information on recreational blue swimmer crab catch and effort in Cockburn Sound during the 2010 fishing season (Dec 15th 2009 – Mar 31st 2010) was obtained by extending the hours of an existing West Coast Creel Survey.

A 12-month creel survey conducted during 1996/97 found recreational catch and effort by shore-based crabbers in Cockburn Sound to be negligible, accounting for less than 1% of the annual catch. Consequently, all creel surveys were restricted to trailered boats launching from public and private boat ramps.

In each boat ramp survey, the bus route method (Robson and Jones, 1989; Jones *et al*., 1990) was used to estimate the recreational catch, effort and size composition of blue swimmer crabs. A survey interviewer visited all boat ramps in a region on the one day (Fig 2.1), and interviewed recreational fishermen about their fishing activities. Interviewers followed a pre-determined schedule specifying the order of boat ramps to visit and the interview time for each boat ramp, with each boat ramp visited during all hours of the interview day during the survey period. A starting boat ramp was selected at random, with the start, travel and wait times at boat ramps rounded to the nearest minute (Table 8.1, 8.2). The bus route method was further constrained so that a shift could not commence part way through the wait time at a ramp (although the probability of commencing at a ramp or travelling remained unchanged), and ended with the completion of the interview period at the last ramp.

Upon arrival at a boat ramp, the number of recreational boat trailers in the car park was recorded along with the prevailing environmental conditions. All recreational boat launches and retrievals during the time period prescribed for that boat ramp were then logged. A second form was used to record catch and effort, biological and demographic information from boat-based fishers who were interviewed when they returned to the boat ramp. Any size or undersize blue swimmer crabs retained aboard a boat were counted, along with the number of male and female crabs returned to the water during the fishing trip. Each crab was sexed and the carapace width (CW) measured between the tips of the lateral points to the nearest millimetre (mm). While survey personnel were instructed to measure all blue swimmer crabs retained by interviewed fishers, occasionally several boats would return to a ramp simultaneously leaving insufficient time to measure all of the crabs in a catch. On these occasions, a random sample was measured as it was considered more important to collect basic catch information from as many fishers as possible. A random sample was also measured when fishers were in a hurry to leave the ramp. The number of recreational trailers was again logged when departing a boat ramp, to validate the number of launch and retrievals recorded during the surveyed period.

The West Coast Creel Survey was conducted between Nov 1st 2007 and Jun 30th 2010 (with dates of the Cockburn Sound creel survey 15 December 2009 to 31 March 2010). The survey covered 61 boat ramps between Kalbarri and Augusta on the west coast of Western Australia, including five boat ramps in Cockburn Sound (Fig. 5.1). The allocation of survey time to each Cockburn Sound ramp was proportional to use by fishers (Table 9.6), as derived from previous studies (Sumner and Williamson, 1999, Sumner and Malseed, 2004). Random start and finish times were selected between 9:00am and 5:00pm for each of the five boat ramps, on 12 sampling days each month. The survey was further stratified by weekday or weekend.

Table 9.6. Allocation of Time to Survey Ramps in Cockburn Sound during the West Coast Creel Survey.

District	Ramp	Prop’n of Time	Time (min)
South Metro	Woodman Point	45%	188
	Sutton Road	30%	41
Rockingham	Kwinana Beach	10%	42
	Palm Beach	25%	103
	Point Peron	30%	124

Evidence from previous recreational crabbing surveys in Cockburn Sound, along with anecdotal accounts from Fisheries Compliance Officers, suggested there may be a significant amount of recreational crabbing taking place in Cockburn Sound in the early morning hours, especially in the Rockingham area. As the wider West Coast Creel Survey was restricted to the hours of 9:00am – 5:00pm, the Cockburn Sound (Early Morning) Creel Survey was also conducted during the 2010 Cockburn Sound blue swimmer crab season to cover the period from sunrise to the commencement of the West Coast survey sample period at 9:00am. Using the methodology employed in the West Coast Creel Survey, the five Cockburn Sound boat ramps were visited between the hours of 5:30am – 9:00am, over 12 randomised days each month between Dec15th 2009 and Mar 31st 2010. The survey was further stratified by weekday or weekend. The allocation of survey time to each Cockburn Sound ramp is presented in Table 9.7.

Table 9.7. Allocation of Time to Survey Ramps in Cockburn Sound during the Cockburn Sound (Early Morning) Creel Survey

Ramp	Prop’n of Time	Time (min)
Woodman Point	30%	42
Sutton Road	5%	7
Kwinana Beach	5%	7
Palm Beach	25%	36
Mangles Bay	5%	7